CHAPTER 8

STORMWATER BEST MANAGEMENT PRACTICES

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Chapter Eight - Stormwater Best Management Practices

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8.1 Overview

8.1.1 Introduction

To comply with federal law, the City of Lincoln is adopting a program to encourage the use of water quality Best Management Practices (BMPs) for new developments and re-development efforts. This chapter provides information and guidance regarding the selection and design of selected BMPs. Studies have documented that implementation of BMPs reduces pollutants in stormwater runoff and receiving waters. They can improve the water quality and environment of the community.

Urban runoff carries with it a wide variety of pollutants from diverse and diffuse sources. Pollutants associated with urban runoff often occur in higher concentrations than found in runoff prior to development. In addition, urban runoff can contain pollutants that are not naturally present in surface runoff from undeveloped land, such as organic pesticides, household solvents, and petroleum products. Runoff from undeveloped basins contains sediment particles, oxygen-demanding compounds, nutrients, metals, and other constituents. Once developed, pollutant loads increase because runoff volumes increase as do sources of the pollutants.

The phenomenon termed "first flush" has often been used to characterize urban runoff. First flush refers to the higher levels of initial concentrations of constituents that are washed off from the surface at the onset of a storm event. A typical pollutant concentration pattern during a storm event contains a relatively high concentration of contaminants during the first flush of runoff. However, depending on rainfall intensity, antecedent period length and conditions, deposition during the antecedent period, and surface characteristics, the affect of the first flush can be varied. After the first flush, the concentration typically drops substantially and fluctuates at a lower level for the remainder of the runoff event. A secondary "spike" in pollutant concentration can occur if a sudden burst of intense rain drives material off surfaces not completely cleaned by the initial runoff (Horner et al., 1994).

8.1.2 Structural and Nonstructural Best Management Practices (BMPs)

Studies such as the Nationwide Urban Runoff Program have documented concentrations of various pollutants in urban runoff (EPA, 1983). To reduce the concentrations and the loads of these pollutants the reach the receiving waters, a system of stormwater BMPs may be implemented. BMPs are defined as measures that function to either keep pollutants from entering stormwater or remove pollutants from stormwater. Various BMPs have been implemented throughout the United States. In general, they can be categorized as either structural or nonstructural. Structural BMPs can be thought of as constructed facilities designed to reduce runoff and/or passively treat urban stormwater runoff before it enters the receiving waters. Nonstructural BMPs consist of pollution prevention BMPs and source control BMPs. Both structural and nonstructural BMPs are used for erosion control during construction as well (UDFCD, 1992). A detailed discussion of sediment and erosion control is presented in Chapter 9.

The selection of the most appropriate BMPs for a given site or basin is largely dependent on whether development is in place or has yet to occur. In areas with existing development, nonstructural BMPs are the most cost-effective because retrofitting structural controls in a developed area can be expensive. Structural controls are more appropriate for new development and significant redevelopment, where they have been integrated into the planning of the infrastructure.

Because non-point source pollution is varied in nature and impact, no individual BMP may fit all situations. It must be tailored to fit the needs of particular sources and circumstances. An effective strategy for minimizing stormwater pollution loads is to use multiple BMPs (structural, nonstructural, and source controls). Multiple BMPs and combining BMPs in series can provide complementary water quality enhancement that minimizes pollutant loads being transported to the receiving waters.

8.2 General Water Quality Management Approach

8.2.1 General Planning and Design Guidelines

The following general planning and design guidelines for structural and nonstructural controls are recommended when developing a water quality control strategy:

- Promote natural infiltration of urban runoff by minimizing onsite impervious areas and preserving natural, broad drainageways.
- Minimize directly connected impervious areas by providing grassed or gravel buffer zones between impervious surfaces. Divert runoff from impervious areas to pervious surfaces before the flows enter surface drainageways.
- Locate structural BMPs in areas that avoid creating a nuisance and the need for increased maintenance.
- Provide multiple access to facilities to improve maintenance capabilities.
- Direct offsite stormwater flow around the onsite facilities.
- Revegetate and/or stabilize all areas disturbed by construction activities and all drainageways created as a part of the development.
- Ensure the plantings and grass cover are firmly established before the owner's obligation is released and maintenance efforts begin.

8.2.2 Effectiveness Of Management Measures

The effectiveness of many management measures was summarized in a 1992 report prepared by the Metropolitan Washington Council of Governments, entitled "A Current Assessment of Urban Best Management Practices." Some of the findings of this report include:

- Not all urban BMPs can reliably provide high levels of removal for both particulate and soluble pollutants. Effective BMPs include wet ponds, stormwater wetlands, multiple pond systems and sand filters. Infiltration BMPs are presumed to be effective in removing pollutants, but are not reliable given their poor longevity. Other BMPs, such as grassed swales, filter strips and water quality inlets, cannot provide reliable levels of pollutant removal until their basic design is significantly enhanced.
- The longevity of some BMPs is limited to such a degree that their widespread use is currently not encouraged. Of particular concern are the infiltration practices, such as basins, trenches and porous pavement. The poor longevity of these BMPs is attributable to a number of factors: lack of pretreatment, poor construction practices, application to infeasible sites, lack of regular maintenance, and in some cases, fundamental difficulties in basic design. Very often the life-spans of BMPs can be increased to acceptable lengths if local communities adopt enhanced designs and commit to strong maintenance and inspection programs.
- No single BMP option can be applied to all development situations and all BMP options require careful site assessment prior to design. Pond options are applicable to the widest range of development situations, but typically require a minimum drainage area. On the other hand, infiltration practices have very limited applications, requiring field verification of soils, water tables, slope and other factors.
- Several BMPs can have significant secondary environmental impacts, although the extent and nature of these impacts is uncertain and site-specific. Pond systems, which offer reliable pollutant removal and longevity, tend to be associated with the greatest number and strongest degree of secondary environmental impacts. Careful site assessment and design are often required to prevent stream warming, natural wetland destruction and riparian habitat modification.
- Relatively limited cost data exist to aid in the assessment of the comparative cost-effectiveness of urban BMP options. Presently, the selections of BMPs is based more on longevity, feasibility, and local design factors than on comparative cost. Maintenance costs may be significant and should be considered during the design process.
- In many cases, a systems approach to BMP design is warranted whereby multiple techniques for runoff attenuation, conveyance, pretreatment, and treatment are utilized.

- Several fundamental uncertainties still exist with respect to urban BMPs. These uncertainties include the toxicity of residuals trapped within BMPs; the interaction of groundwater and BMPs (both ponds and infiltration); and the long-term performance of urban BMPs. The USEPA has evaluated the benefits of water quality BMP's and their associated uncertainties and have determined that municipalities should encourage implementation of structural and non-structural BMP's.

Based on the above findings, it is clear how important it is to carefully plan and design BMPs on a site-specific basis. Success in applying any management practice depends on selecting the appropriate option for the control objectives, specific conditions at the site, proper implementation and maintenance.

8.3 Structural Best Management Practices

8.3.1 Pollutant Removal Mechanisms

Although runoff may contain many individual pollutants, they can, in general, be grouped into two categories: particulate and soluble. Often, pollutants such as metals and oxygen demand compounds become adsorbed or attached to particulate matter. Therefore, if the particulate matter is removed, so are the adsorbed or attached constituents.

There are four basic pollutant removal or immobilization mechanisms promoted by the BMPs described in this chapter. The following is an overview of each of them:

- Sedimentation - Particulate matter is, in part, settled out of urban runoff. Approximately 80 percent of metals in stormwater are attached or adsorbed to particles that are under 60 microns in diameter (i.e., fine silts and clays). Consequently, these particles can require long periods of time to settle out of suspension. With extended detention, however, the smaller particles can agglomerate into larger ones, thus removing a larger proportion of them through sedimentation.
- Filtering - Particulates can be removed from water by filtration. Filtration removes particles by attachment to small-diameter collectors such as sand.
- Infiltration - As surface runoff infiltrates or percolates into the ground, pollutant loads are removed or reduced in the runoff. Particulates are removed at the ground surface by filtration, and soluble contaminants can be adsorbed to the soil matrix as the runoff percolates into the ground. Soil characteristics such as permeability, cation exchange capacity, and depth to groundwater or bedrock limit the effectiveness of infiltration as a pollutant removal mechanism.
- Biological Uptake - Soluble constituents can be ingested or taken up from the water column and concentrated through bacterial action and phytoplankton growth. In addition, certain biological activities can reduce toxicity of some pollutants.

8.3.2 Structural BMP Selection

Selecting the appropriate BMP for a site depends on several factors, including:

- The permeability and type of soil underlying the BMP;
- The size of the tributary basin and the generated runoff volume in relation to the size of the BMP;
- The slopes and geometry of the site;
- The amount of base flow;
- The proximity of bedrock to the surface;
- The proximity to the seasonal high groundwater table to the surface;
- Tributary basin land uses; and
- The ability to handle high sediment loads.

8.3.3 Water Quality Control Volume

For many BMPs, combining the water quality facility with a flood control facility is practical and cost effective. Specifically, the water quality control volume (WQCV) that is recommended for control is the first half inch (0.5 inches) of runoff from the basin tributary to the BMP. For facilities that combine water quality control with flood control, the runoff from the design storms for the flood control criteria should be "stacked" on top of the water quality control volume. The water quality control volume should be detained over at least a 24-hour period, and preferably for longer.

8.3.4 Structural BMP Descriptions

This section gives information regarding the applicability, pollutant removal efficiencies, advantages, disadvantages, costs and maintenance considerations for structural BMPs that could be used within the City of Lincoln. Other structural BMP's may also be applicable for use in the City.

The structural BMPs covered in this chapter include:

- Extended Dry Detention Basins
- Constructed Wetlands
- Filter Strips and Flow Spreaders
- Infiltration Trenches
- Oil/Grit Separators
- Retention (Wet) Ponds
- Grassed Swales
- Sand Filters
- Porous Pavement
- Catch Basin Inserts

For each BMP, performance data are included to give a general idea of the pollution removal rates of different BMPs. These values are presented for comparison of BMPs only and are subject to wide variability when describing specific BMPs.

8.3.4.1 Extended Dry Detention Basins

Extended dry detention (ED) basins are designed to completely empty at some time after stormwater runoff ends. These are adaptations of the detention basins used for flood control. The primary difference is in outlet design; the extended basin uses a much smaller outlet that extends the retention time for more frequent events so that pollutant removal is facilitated. A 40-hour drain time for the WQCV is recommended to remove a significant portion of fine particulates and provide streambank erosion control (UDFCD, 1992; Schueler, 1987). The term "dry" implies that there is no significant permanent water storage (UDFCD, 1992).

Many designers encourage a two stage design in which the upper stage is dry except for infrequent large storm events and the lower stage is regularly inundated, with a volume equal to the runoff from the mean storm.

<u>General applicability and experience with technique elsewhere</u>

a. Typical Applications
   - Significant areal requirement limits use; not typically a site-based BMP.
   - Retrofitting to established developments may be very difficult due to areal requirements.
   - Extended dry detention basins can reduce peak stormwater runoff rates while trapping sediment loads, particularly when used downstream from construction sites. Sediment from such high loads will need to be removed, however. ED basins can be used to improve runoff water quality from roads, parking lots, residential, commercial and industrial areas. Typically, they are used in conjunction with other onsite BMPs.

b. Design Considerations (See Figures 8-1 through 8-3 for representative schematics)
   - Land requirement is typically 0.5 to 2.0 percent of drained area (UDFCD,1992)
   - The volume of runoff detained should be based on 0.5 inches of runoff from the tributary area.

- Pilot channel should be constructed to minimize erosion control (alternately use turf if little low flow). Size such that any event runoff will overflow the low flow channel onto the pond floor.
- Side slopes shall be no greater than 4:1 if mowed.
- Inlet and outlet located to maximize flow length.
- Design for full development upstream of control.
- Rip-rap protection (or other suitable erosion control means) for the outlet and all inlet structures into the pond.
- Use a water quality outlet that is capable of slowly releasing the WQCV over a 40-hour period. A perforated riser can be used in conjunction with a weir box opening above it to control for larger storm outflows. A sample outlet is illustrated in Figure 8-2. The number of perforations per row can be determined with the aid of Figure 8-3. This relationship is based on the rows being equally spaced vertically at 4 inches on center. Any other outlet that can meet the emptying time criteria should be acceptable (UDFCD,1992).
- One foot of freeboard above peak stage for top of embankment for design storm.
- Emergency spillway designed to pass the 100-year storm event.
- Maintenance access (< 8 % slope and approximately 10 feet wide).
- Trash racks, filters or other debris protection on control and anti-vortex plates.
- Insure no outlet leakage and use anti-seep collars.
- Benchmark for sediment removal.
- Two stage design (top stage - dry during the mean storm, bottom stage - inundated during storms less than the mean storm event.)
- Top stage shall have slopes between 2% and 5% and a depth of 2 to 5 feet.
- Design as off-line pond to bypass larger flows.
- Design as sediment settling basin for pretreatment of the larger particles.
- Addition of a small wetland marsh or ponding area in the basin's bottom may enhance soluble pollutant removal, however storms may flush out trapped sediments and minimize this benefit.
- The facility must also meet the criteria provided in Chapter 6 Storage Facilities.

c. Other Experiences with BMP

- Extended dry detention basins have performed well in sediment and associated pollutant removal efficiencies. They also prevent streambank erosion. Problems noted include clogging of the outlet and detention times significantly lower than design (Galli, 1992).

Reported pollutant removal efficiencies

- Reported data

EPA,1986; Grizzard et al., 1986; Whipple and Hunter, 1981:

Suspended Solids	50-70%
Total Phosphorus	10-20%
Total Nitrogen	10-20%
Zinc	30-60%
Bacteria	50-90%
Lead	75-90%

Galli, F.J., 1992:

Lead	62%
Zinc	57%

- For soluble pollutants (e.g. phosphorous, nitrogen, zinc), the removal performance appears to be more consistent than for retention ponds or wetlands, although the latter have higher maximum removal rates. Removal rates for less soluble constituents are somewhat less than those for retention ponds or wetlands (Urbonas and Stahre, 1993).

Stormwater BMPs

- Due to the wide range of variability for pollutant removal, a conservative estimate near the low end of the ranges reported should be assumed.

Advantages

- Moderate to high removal of particulates and suspended heavy metals.
- Infiltration and resultant recharge to ground water is minimal compared to infiltration type BMPs, therefore the risk of direct introduction of contaminants to ground water is also minimal.

Disadvantages

a. Human Risk, Public Safety and Potential Liability
b. Environmental Risk and Implications
   - Possible habitat destruction
   - High ground water levels may inundate the basin and outlet (use retention ponds if this is the case); ground water mounding may occur with slow-draining or silt-clogged soils.
   - Thermal modification to downstream waters should be minimal (Schueler, 1987)
c. Other
   - Will likely have negative aesthetics unless a lower-stage basin is used.
   - Can become a trash dump if not maintained.
   - Potential breeding grounds for mosquitos and other insects unless a balanced habitat is established.
   - Aesthetics; must factor in debris and sediment accumulation and removal, as well as overall design integration with site.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
   - Exfiltration will tend to decrease over time as the bottom becomes clogged with sediment; this may be a positive factor in preventing ground water contamination.
b. Routine and Non-routine Maintenance
   - Cleanup of debris and trash, pest and overgrowth control, erosion repairs, inspect for structural damage to outlets, clogging of outlet.
   - A five to ten year sediment cleanout cycle is recommended (Schueler, 1987).
c. Sustainability of Maintenance or Program Management
   - Regular maintenance and sediment cleanout are not technically difficult; long-term management should not be problematic.

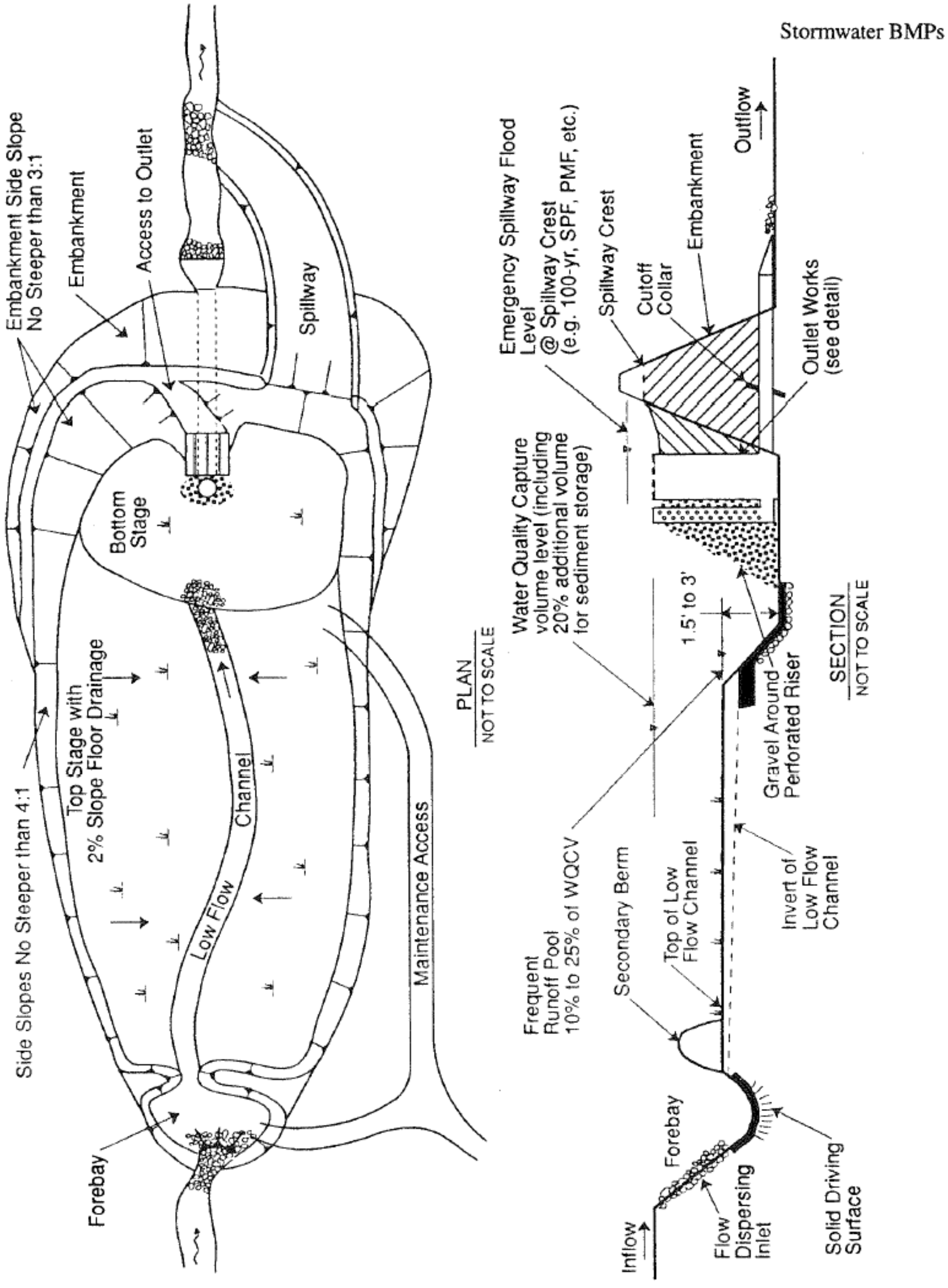
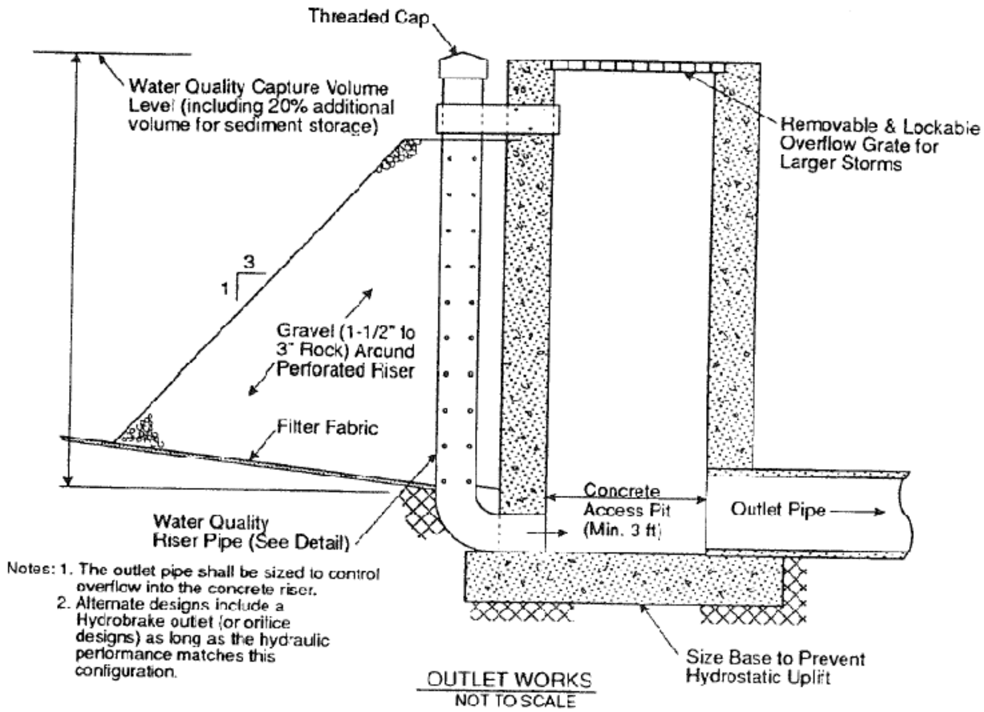
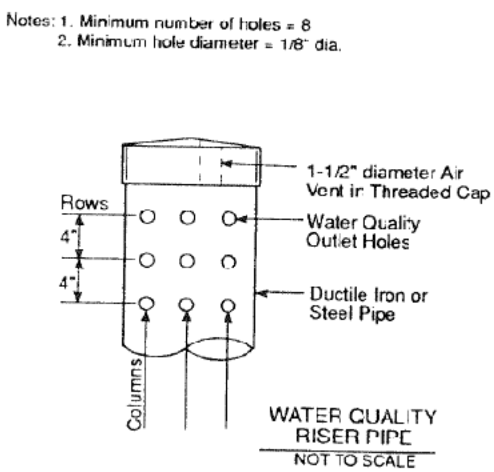


Figure 8-1 Extended Dry Detention Basin

Source: Denver Urban Drainage and Flood Control District, 1992





Maximum Number of Perforated Columns				
Riser Diameter (in.)	Hole Diameter, in.			
	1/4"	1/2"	3/4"	1"
4	8	8	--	--
6	12	12	9	--
8	16	16	12	8
10	20	20	14	10
12	24	24	18	12

Hole Diameter (in.)	Area of Hole ($in.^2$)
1/8	0.013
1/4	0.049
3/8	0.110
1/2	0.196
5/8	0.307
3/4	0.442
7/8	0.601
1	0.785

Figure 8-2 Water Quality Outlet for Extended Dry Detention Basin

Source: Denver Urban Drainage and Flood Control District, 1992

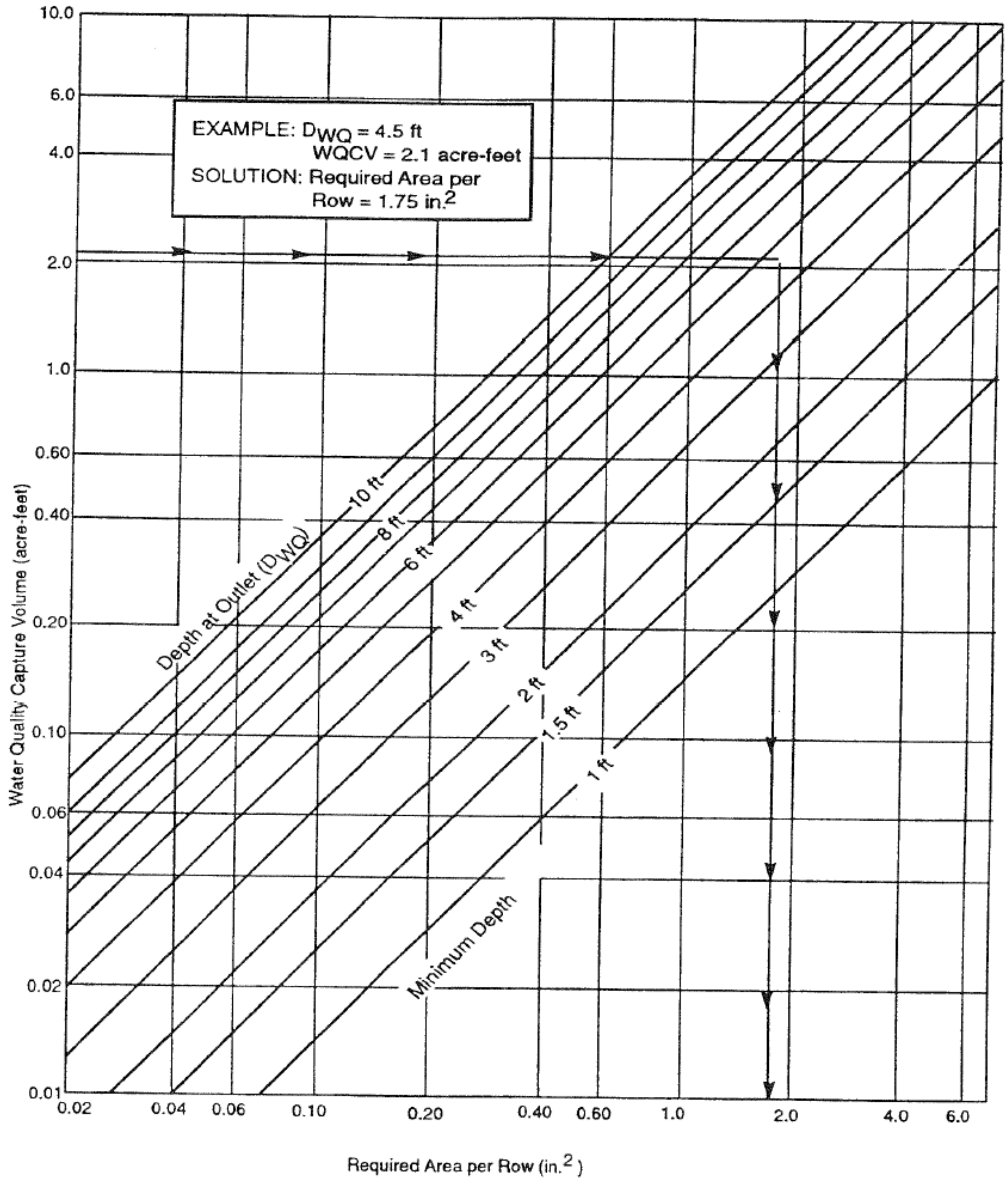


Figure 8-3 Water Quality Outlet Sizing for Extended Dry Detention Basin with 40 Hour Drain Time of the Capture Volume

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.2 Retention (Wet) Ponds

A retention pond is designed to not completely drain as in the dry basin design. A permanent pool of water is replaced in part by stormwater during an event. For water quality purposes, the design is such that the WQCV is released over 12 to 24 hours, but the hydraulic residence time (HRT) for the permanent pool volume is two weeks or longer. Reduction of volume in the permanent pool is through evapotranspiration and infiltration only. A dry weather base flow may be required to maintain the permanent pool (UDFCD, 1992).

General applicability and experience with technique elsewhere

a. Typical Applications
- Typically not a site-based BMP, but retention ponds are effective in most settings where adequate open area exists. Due to the area required, it is difficult to retrofit to a completely developed watershed.
- Since evaporation can quickly dry up base flows, retention ponds work best in areas with low ET rates and/or non-arid climates.
- Wet retention ponds can reduce peak stormwater runoff rates while trapping sediment loads, as well as provide some biological uptake of nutrients. They can be used downstream from construction sites, but sediment removal is difficult. They can be used to improve runoff water quality from roads, parking lots, residential, commercial and industrial areas. Typically, they are used in conjunction with other onsite BMPs.

b. Design Considerations (See Figures 8-4 through 8-6 for representative schematics)
- Minimum length to width ratio of 3:1 (preferably wedge shaped expanding outward toward the outlet). Irregular shorelines for larger ponds provide visual variety.
- Inlet and outlet located to maximize flow length. Use baffles to increase flow length if needed.
- Minimum depth of permanent pool 2 to 3 feet, maximum depth of 9 to 10 feet. Average depth should be 3 to 6 feet.
- Design for full development upstream of control.
- Side slopes shall be no greater than 4:1.
- Rip-rap protection (or other suitable erosion control means) for the outlet and all inlet structures into the pond. Individual boulders or baffle plates can work for this.
- Minimum drainage area of 10 acres. Land requirement is typically 0.5 to 2.0 percent of drained area (UDFCD,1992).
- Use a water quality outlet that is capable of slowly releasing the WQCV over a 12-hour period. A perforated riser can be used in conjunction with a weir box opening above it to control for larger storm outflows. A sample outlet is illustrated in Figure 8-5. The number of perforations per row can be determined with the aid of Figure 8-6. This relationship is based on the rows being equally spaced vertically at 4 inches on center. Any other outlet that can meet the emptying time criteria should be acceptable (UDFCD,1992).
- Emergency drain; i.e. sluice gate, drawdown pipe; capable of draining within 24 hours.
- Trash racks, filters, hoods or other debris control on riser.
- Maintenance access (< 8 % slope and 10 feet wide).
- Benchmark for sediment removal.
- Design for multi-function as flood control and extended detention.
- Sediment forebay for larger ponds (often designed for 5 to 15 percent of total volume). Forebay should have separate drain for de-watering. Grass biofilters for smaller ponds.
- Incorporating a wetland design or wetland vegetation into the pond can increase contaminant removal rates. This may also encourage wildlife habitation which can help in mosquito and pest control.
- If fast draining soils are present, a liner may be needed to sustain baseflow; conversely, if bedrock is present and needs to be excavated, construction costs may become very high.
- The facility must also meet the criteria provided in Chapter 6 Storage Facilities.

c. Other Experiences with BMP
- Wet retention ponds are generally more effective at removing nutrient loadings than dry basins; their use is encouraged where nutrient loads are a major contributor to water quality problems (Hartigan, 1989)
- According to the NURP study, basins which exhibit high removal efficiencies are sized such that the mean storm displaces only about 10% of the available volume, and overflow rates (mean runoff rate/basin surface area) are a small fraction of the median particle settling velocity (EPA, 1993). The study concluded that retention ponds are capable of providing very effective removal of pollutants in urban runoff.

Reported pollutant removal efficiencies

- Reported data

EPA,1983:

Suspended Solids	91%
Total Phosphorus	0-80%
Total Nitrogen	0-80%
Zinc	0-70%
Lead	9-95%
BOD	0-69%

Yousef, Y.A., et al. 1986:
A well-oxygenated pond with minimum organic debris appears to provide the environment for improved removal efficiencies of nutrients and selected heavy metals. Also, it was concluded that slower infiltration rates and increased mean residence time favor retention of metals within the sediments. There was no evidence of metals migration within the sediments or that a contamination hazard exists to nearby surface or ground water.

Dissolved Lead	54.5%
Particulate Lead	95.1%
Dissolved Zinc	88.3%
Particulate Zinc	96.2%
Dissolved Copper	49.7%
Particulate Copper	77.0%
Dissolved Phosphorous	90.1%
Particulate Phosphorous	11.4%
Organic Nitrogen	11.0%
Ammonia	81.6%
Nitrates + Nitrites	86.5%

Hartigan 1989:
Reported expected removal rates of 40 - 60% for phosphorous and 30 - 40% for nitrogen. Additionally, a minimum Basin area/tributary area ratio of 1% is recommended for high removal rates; 3% for poorly draining soils.

Advantages

- Cost-effective for larger tributary watersheds
- Moderate to high removal rates of many urban pollutants
- Creates wildlife habitat

Stormwater BMPs

- Provides recreation, aesthetics, open space areas
- More efficient sedimentation than dry basin, since outlet is above the basin bottom, leaving a 'dead zone' to trap sediment
- Infiltration and resultant recharge to ground water is minimal compared to infiltration type BMPs, therefore the risk of direct introduction of contaminants to ground water.

<u>Disadvantages</u>

a. Human Risk, Public Safety and Potential Liability
b. Environmental Risk and Implications
   - Attract waterfowl, which may increase downstream nutrient loading and bacteria.
   - Inadequate base flow can cause very high concentrations of salts, nutrients, and algae through evaporation, resulting in significant downstream loadings from smaller events.
   - Possible low DO effluent, stream warming, trophic shifts, habitat destruction, loss of upstream channels.
   - Large events or low dissolved oxygen content can cause mixing or resuspension of deposited sediments, increasing turbidity and metals concentrations.
c. Other
   - Higher cost than conventional stormwater detention.
   - Difficult sediment removal.
   - Floating litter, scum and algal blooms, odors, insects.
   - Bottom of pool may need to be lined to maintain permanent pool in well-draining conditions.
   - Wet retention ponds have greater storage capacity requirements than dry ED basins, resulting in higher capital costs.
   - Large basins may require a dam safety permit.

<u>Maintenance/monitoring/enforcement considerations</u>

a. Reliability and Consistency over Time
   - May be more efficient over time due to increased vegetation providing enhanced nutrient and metals removal rates

b. Routine and Non-routine Maintenance
   - Sediment to be removed when 20% of storage volume of the facility is filled (design storage volume must account for volume lost to sediment storage).
   - No woody vegetation shall be allowed on the embankment without special design provisions.
   - Other vegetation over 18 inches high shall be cut unless it is part of planned landscaping.
   - Debris shall be removed from blocking inlet and outlet structures and from areas of potential clogging.
   - The control shall be kept structurally sound, free from erosion, and functioning as designed.
   - Control of scum and algal blooms, odors, insects.
   - The site should be inspected and debris removed after every major storm.
c. Sustainability of Maintenance or Program Management
   - Funds must be budgeted for routine and non-routine maintenance, particularly considering the high cost of sediment removal. For this reason, public rather than private maintenance is preferred (Schueler, 1987).

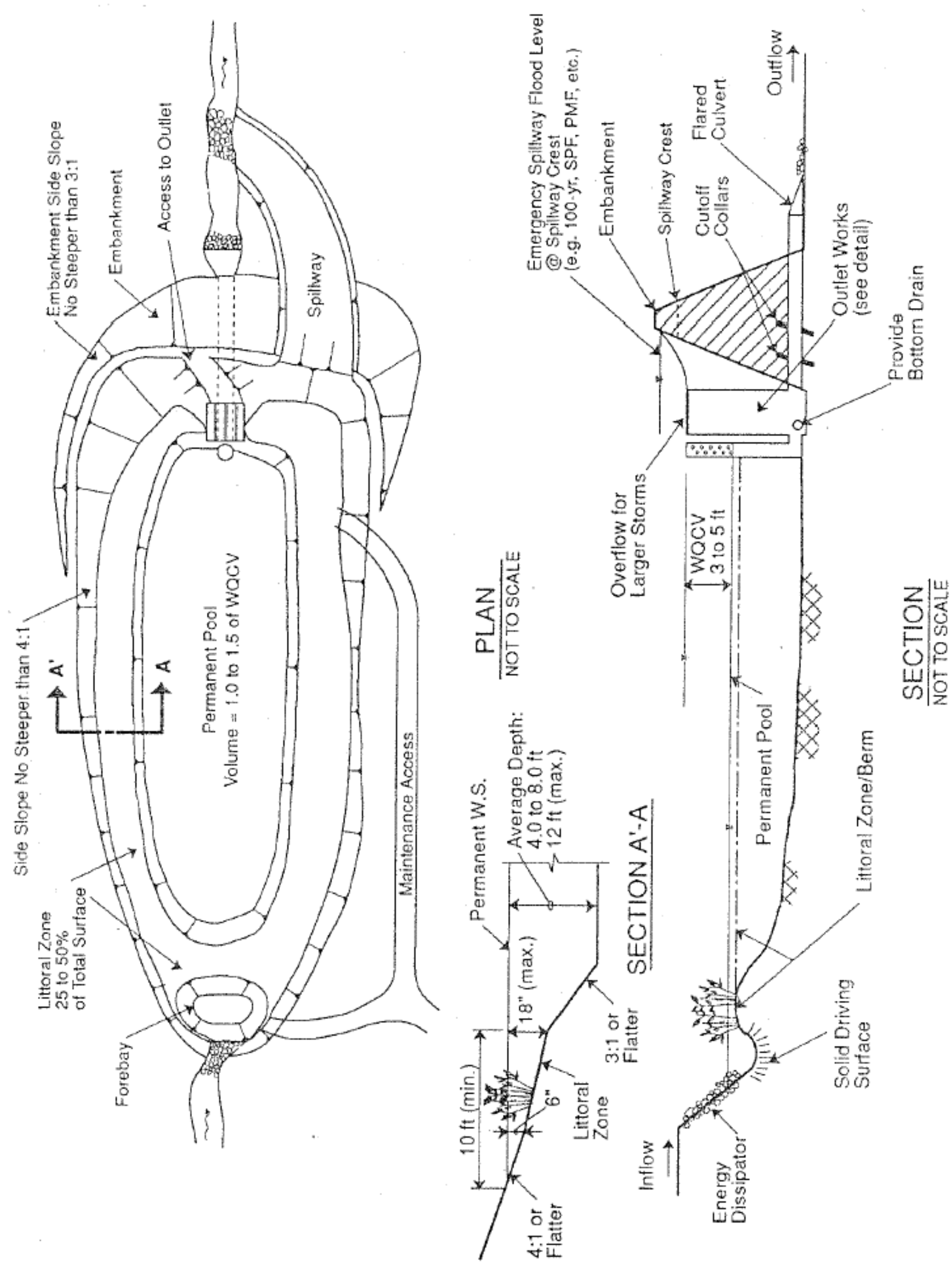
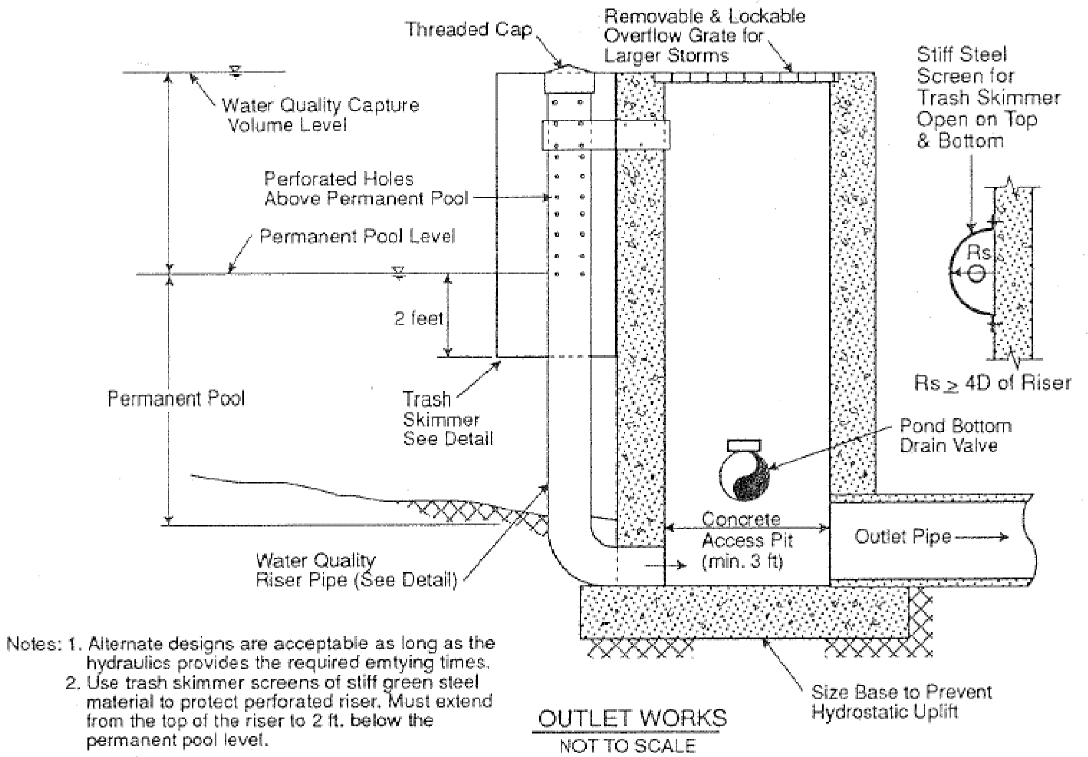
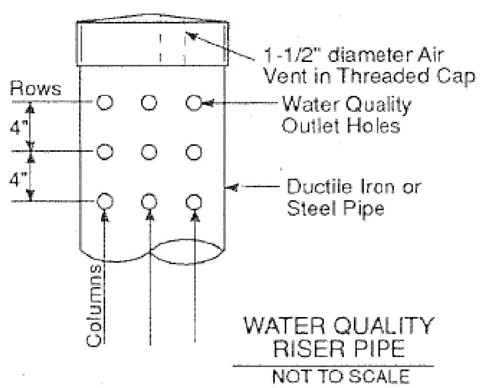


Figure 8-4 Retention (Wet) Pond

Source: Denver Urban Drainage and Flood Control District, 1992



Notes: 1. Minimum number of holes = 8
2. Minimum hole diameter = 1/8" Dia.



Maximum Number of Perforated Columns				
Riser Diameter (in.)	Hole Diameter, inches			
	1/4"	1/2"	3/4"	1"
4	8	8	--	--
6	12	12	9	--
8	16	16	12	8
10	20	20	14	10
12	24	24	18	12

Hole Diameter (in.)	Area (in. 2)
1/8	0.013
1/4	0.049
3/8	0.110
1/2	0.196
5/8	0.307
3/4	0.442
7/8	0.601
1	0.785

Figure 8-5 Water Quality Outlet for Retention Pond

Source: Denver Urban Drainage and Flood Control District, 1992

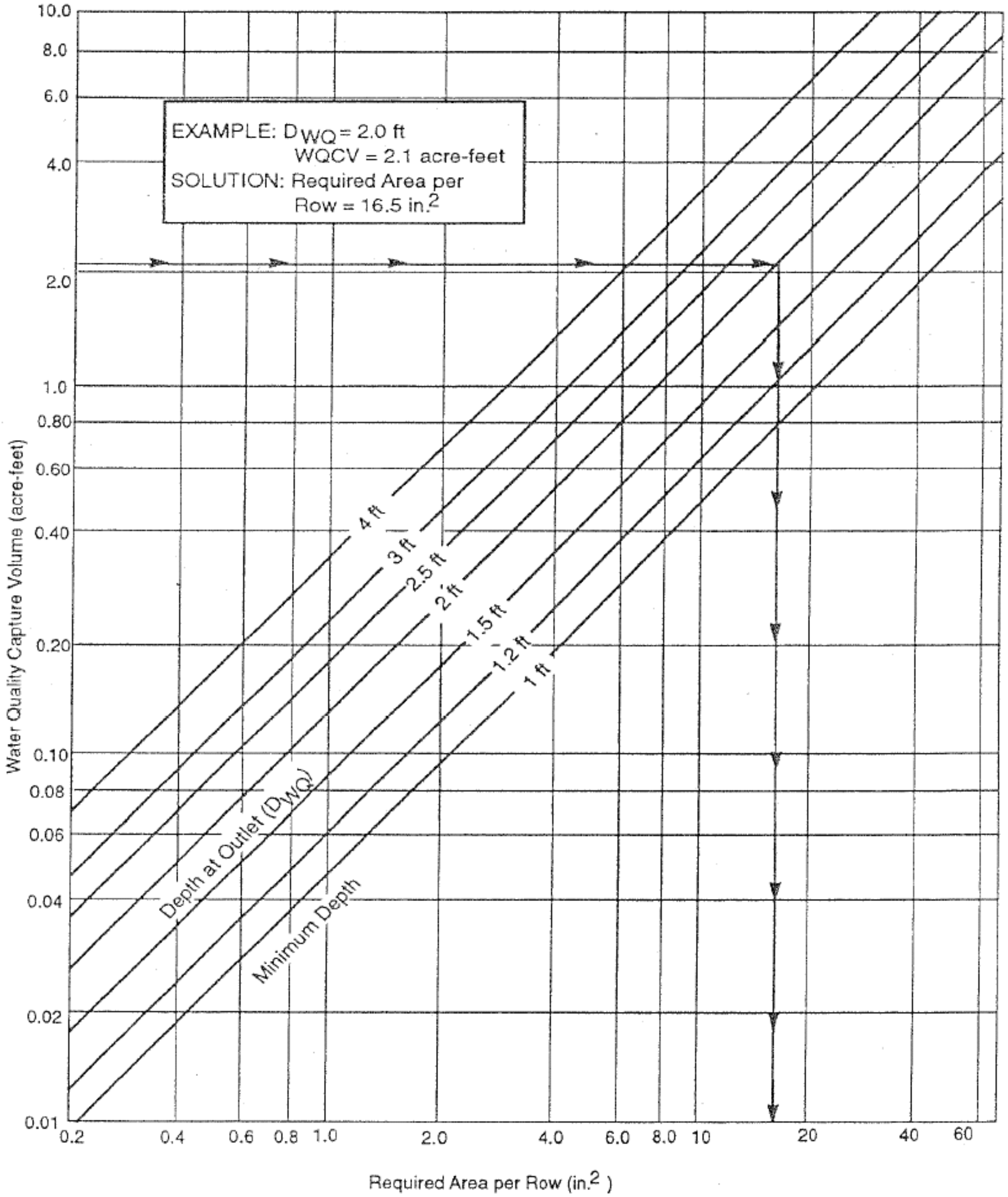


Figure 8-6 Water Quality Outlet Sizing for Retention Pond with 12 Hour Drain Time of the Capture Volume

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.3 Constructed Wetlands

Constructed wetlands can take the form of very shallow retention ponds or wetland-bottomed channels. A perennial base flow is needed to encourage the growth of wetland species such as rushes, willows, cattails, and reeds. These slow runoff and promote settling and biological uptake. "Pocket" wetlands are typically under a tenth of an acre in size, serving developments of 10 acres or less. These are usually less reliable and efficient than larger wetlands.

General applicability and experience with technique elsewhere

a. Typical Applications
- Wetland basins can be used as a follow-up BMP in a watershed, or as an onsite facility if the owner can provide sufficient water. Flood control measures may be instituted above the wetland basin.
- Retrofitting to established developments may be very difficult due to areal requirements.
- Arid climates or high ET rates can make maintenance of the required base flow difficult. Also, short growing seasons may inhibit vegetation growth and propagation.
- Wetland bottom channels can be used in two ways: first, a wetland can be established in a man-made channel and can act as both a conveyance facility and a water quality enhancement facility. Perhaps the more effective option is to locate the channel downstream of a stormwater detention facility that will remove much of the sediment load. The channel then provides better quality water to the receiving water body. The detention facility should have at least a 24 hour drain period for the storm event.

b. Design Considerations (See Figures 8-7 through 8-8 for representative schematics)
- A water budget analysis is needed to ensure the adequacy of the base flow. Also, loamy soils are needed to permit rooting of plants. A near-zero longitudinal slope is required.
- Designed for an extended detention time of 24 hours.
- Surface area of the wetland should account for a minimum of 3 percent of the area of the watershed draining into it.
- The length to width ratio should be at least 2 to 1.
- A soil depth of at least 4 inches shall be used for shallow wetland basins.
- Approximately 75 percent of the wetland should have water depths less than 12 inches, and 25 percent of the wetland should have depths ranging from 2 to 3 feet. Of the 75 percent of the wetland that should be 12 inches deep or less, it is recommended that approximately 25 percent range from 6 inches deep to 12 inches deep, and that the remaining 50 percent be 6 inches or less in depth.
- The deeper area of the wetland should include the outlet structure so outflow from the basin is not interfered with by sediment buildup.
- A forebay should be established at the pond inflow points to capture larger sediments and be 4 to 6 feet deep. Direct maintenance access to the forebay should be provided with access 15 feet wide minimum and 5:1 slope maximum. Sediment depth markers should be provided.
- If high water velocity is a potential problem, some type of energy dissipation device should be installed.
- The designer should maximize use of pre- and post-grading pondscaping design to create both horizontal and vertical diversity and habitat.
- A minimum of 3 aggressive wetland species (obligate wetland species) of vegetation should be planted 2 feet on center within the area of wetland that contains approximately 6 inches of water or less.
- Three additional wetland species (facultative wetland species) of vegetation should be planted in clumps of 5 in saturated soil outside of the obligate wetland area with a spacing of 3 feet on center.
- Wetland mulch, if used, should be spread over the high marsh area and adjacent wet zones (-6 to +6 inches of depth) to depths of 3 to 6 inches.
- A minimum 25-foot buffer, for all but pocket wetlands, should be established and planted with riparian and upland vegetation (50-foot buffer if wildlife habitat value required in design).
- Surrounding slopes should be stabilized by planting in order to trap sediments and some pollutants and prevent them from entering the wetland.

- A written maintenance plan should be provided and adequate provision made for ongoing inspection and maintenance, with more intense activity for the first three years after construction.
- The wetland should be maintained to prevent loss of area of ponded water available for emergent vegetation due to sedimentation and/or accumulation of plant material.
- To minimize maintenance as much as possible, it is recommended that wetland basins be installed on stabilized watersheds and not be used for sediment control.
- Complex topography can be maintained by bioengineering methods (such as fascines) or straw bales and geotextile rolls.
- It is recommended that the frequently flooded zone surrounding the wetland be located within approximately 10 to 20 feet from the edge of the permanent pool.
- The wetland should be designed to allow slow percolation of the runoff through the substrate (add a layer of clay for porous substrates).
- The depth of the forebay should be in excess of 3 feet and contain approximately 10 percent of the total volume of the normal pool.

c. Other Experiences with BMP

- Wetlands for storm water treatment have been used for 10 to 15 years. Estimates for removal rates vary widely in the literature, probably due to a lack of data that would produce design protocols. Some higher removal rates may be the result of testing in experimental wetlands and from wastewater treatment sites which have much higher concentrations of BOD and nutrients.
- Pollutant removal efficiencies appear to vary greatly depending on design and environment.

<u>Reported pollutant removal efficiencies</u>

- Reported data

USGS, 1986 (based on 13 sampled runoff events in Orlando, Florida):

Suspended Solids	40-94%
Total Nitrogen	0-21%
Zinc	(-29)-82%
Lead	27-94%
BOD	18%

Lakatos and McNemer, 1987:

Total Phosphorus	(-4)-90%

Wright Water Engineers, 1991:

Manganese	36-77%
Suspended Solids	29-92% (71% average on eight projects)

- Claims of high removal rates of nutrients from stormwater are not substantiated by data; these claims may be based on data from experimental wetlands and from wastewater removal rates, where influent concentrations are much higher.
- Nitrification and Denitrification are dependent on many variables, with detention time perhaps the most significant; Shaver (1994) recommends 14 days.

Stormwater BMPs

Advantages

- Aesthetics, wildlife habitat, erosion control, pollutant removal

Disadvantages

a. Environmental Risk and Implications
   - Possible stream warming, natural wetlands alteration
   - Salts and scum may accumulate and be flushed out with a major storm event.
   - Possible breeding ground for pests, mosquitos. However, the Maryland study (Galli, 1992) found no mosquito larvae at any of nine sites surveyed, and there is evidence that this is the norm for constructed wetlands.
   - Effectiveness at removing nitrogen and some forms of phosphates is questionable.

b. Other
   - Need for periodic sediment removal to maintain proper distribution of growth zones and water movement.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
   - Difficult to determine, but with proper design and maintenance the wetland should perform well for an indefinite period of time.

b. Routine and Non-routine Maintenance
   - Proper depth and spatial distribution of growth zones must be maintained
   - Remove unwanted vegetation, debris and litter, accumulated sediment and organic muck.

c. Sustainability of Maintenance or Program Management
   - Maintenance is generally greatest during the first three years in order to establish vegetation.

Stormwater BMPs

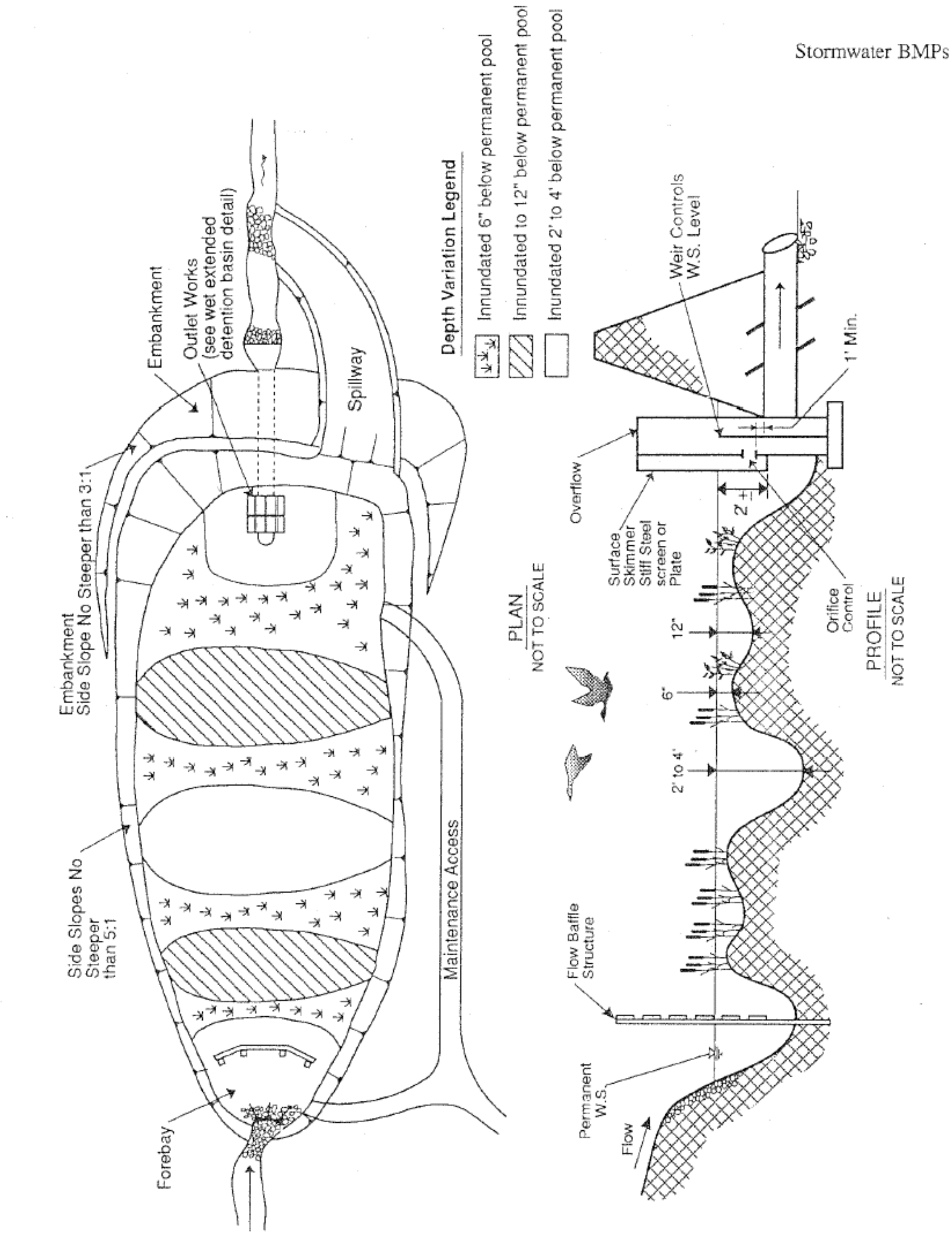
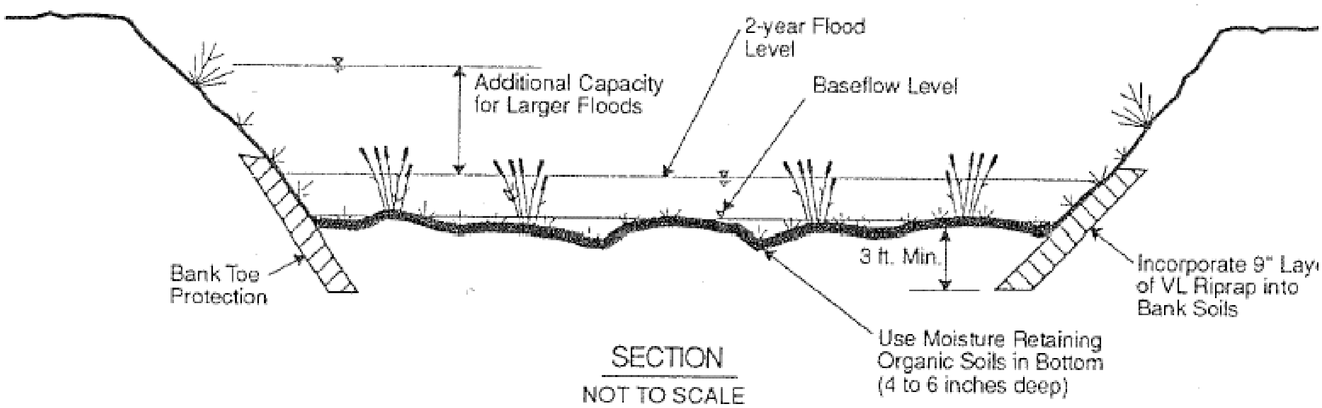


Figure 8-7 Plan and Profile of Wetland Pond

Source: Denver Urban Drainage and Flood Control District, 1992



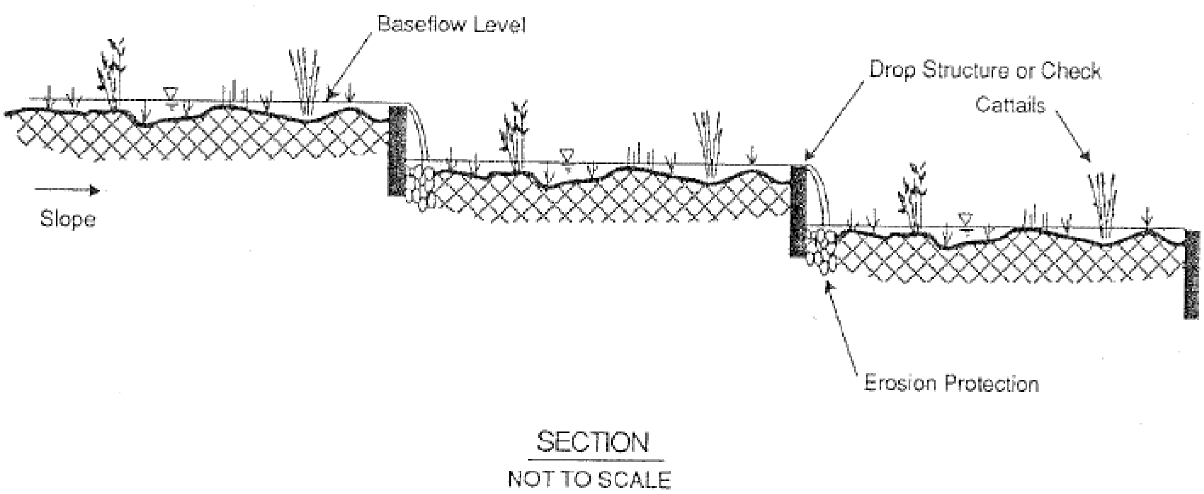


Figure 8-8 Plan and Section of Wetland Channel

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.4 Grassed Swales

Grassed swales are densely vegetated drainageways with low-pitched sideslopes that collect and slowly convey runoff. The emphasis is on slow, shallow flow that encourages sedimentation and discourages erosion. They are set lower than the surrounding ground level, allowing runoff to enter the swales over grassy, shallow banks. Check dams may be used in conjunction with the swales to further slow the runoff. If base flow is present, wetland vegetation may also develop.

General applicability and experience with technique elsewhere

a. Typical Applications
  - Swales are often used to collect overland flow from impervious areas such as parking lots, buildings and roadways, as well as semi-previous areas such as grass filter strips and residential yards. They are often presented as an option to curb-and-gutter systems in order to reduce peak flow rates and reduce pollutant loading downstream. A follow-up BMP will be required to enhance water quality.

b. Design Considerations (See Figures 8-8 for representative schematic)
  - Generally well adapted for sites with ground slopes up to 3 or 4 percent, and not over 6 percent. The longitudinal slope of the swale should be less than 1 percent.
  - Limited to runoff velocities less than 1.5 to 2.5 ft/s.
  - Maximum design flow depth to be approximately 3 foot.
  - Swale cross-section should have side slopes of 4:1 (h:v) or flatter.
  - Underlying soils should have a high permeability.
  - Swale area should be tilled before grass cover is established.
  - Dense cover of a water tolerant, erosion resistant grass should be established over swale area.
  - As a BMP, grassed swales are best suited to residential or institutional areas where percentage of impervious area is relatively small.
  - Check dams can be installed in swales to promote additional infiltration. Recommended method is to sink a railroad tie halfway into the swale. Riprap stone should be placed on the downstream side to prevent erosion.
  - The NURP study concluded that adequate residence times are key to significant pollutant removal, although parameters were not determined.

c. Other Experiences with BMP
  - A New Hampshire NURP project showed heavy metal reductions of approximately 50% and COD, nitrate, and ammonia reductions around 25%.
  - Primarily an infiltration practice, so that soluble pollutants may be directed to the ground water.
  - Removal efficiencies vary widely; the reasons for this are not well understood.

Reported pollutant removal efficiencies

- Reported data

Whalen and Callum, 1988:	
TSS	80%
Oakland, P.H., 1983:	
Cadmium, total	56%
Cadmium, dissolved	42%
Zinc, dissolved	47%
Copper, dissolved	53%
Lead, dissolved	63%

Schueler, et al., 1992 (for low gradient swales with check dams):

Stormwater BMPs

TSS	60-80%
Total Phosphorus	20-40%
Total Nitrogen	20-40%
BOD	20-40%
Metals	60-80%

- The key to pollutant removal may be soils with high infiltration rates and flow velocities of less than 0.5 ft/sec. (Urbonas and Stahre, 1993). This may be inappropriate for areas with high ground water tables.
- Filtration, adsorption, and ion exchange may occur in the underlying soils, reducing the potential for ground water contamination.

Advantages

- Aesthetics.
- Effective in reducing runoff in small storm events where other BMPs are less effective.
- Can be used to limit the extent of directly connected impervious areas.

Disadvantages

a. Human Risk, Public Safety and Potential Liability
   - Potential for soggy yards, mosquito breeding, and more right-of-way requirement than for equivalent storm sewers.

b. Environmental Risk and Implications
   - Particularly with small storm events, the primary removal mechanism is infiltration; in areas of high ground water vulnerability, this may not be a good option.

c. Other
   - Effectiveness is limited by infiltration capacity of soils; conversely, well-draining soils may direct polluted runoff directly to ground water.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
   - Dependent on proper design and maintenance

b. Routine and Non-routine Maintenance
   - Routine maintenance; grass must be mowed, some litter removal, sediment removal to maintain channel flow capacity.
   - Non-routine maintenance: replacement of damaged grass.

c. Sustainability of Maintenance or Program Management
   - Maintenance must be included in the budget to insure proper operation.

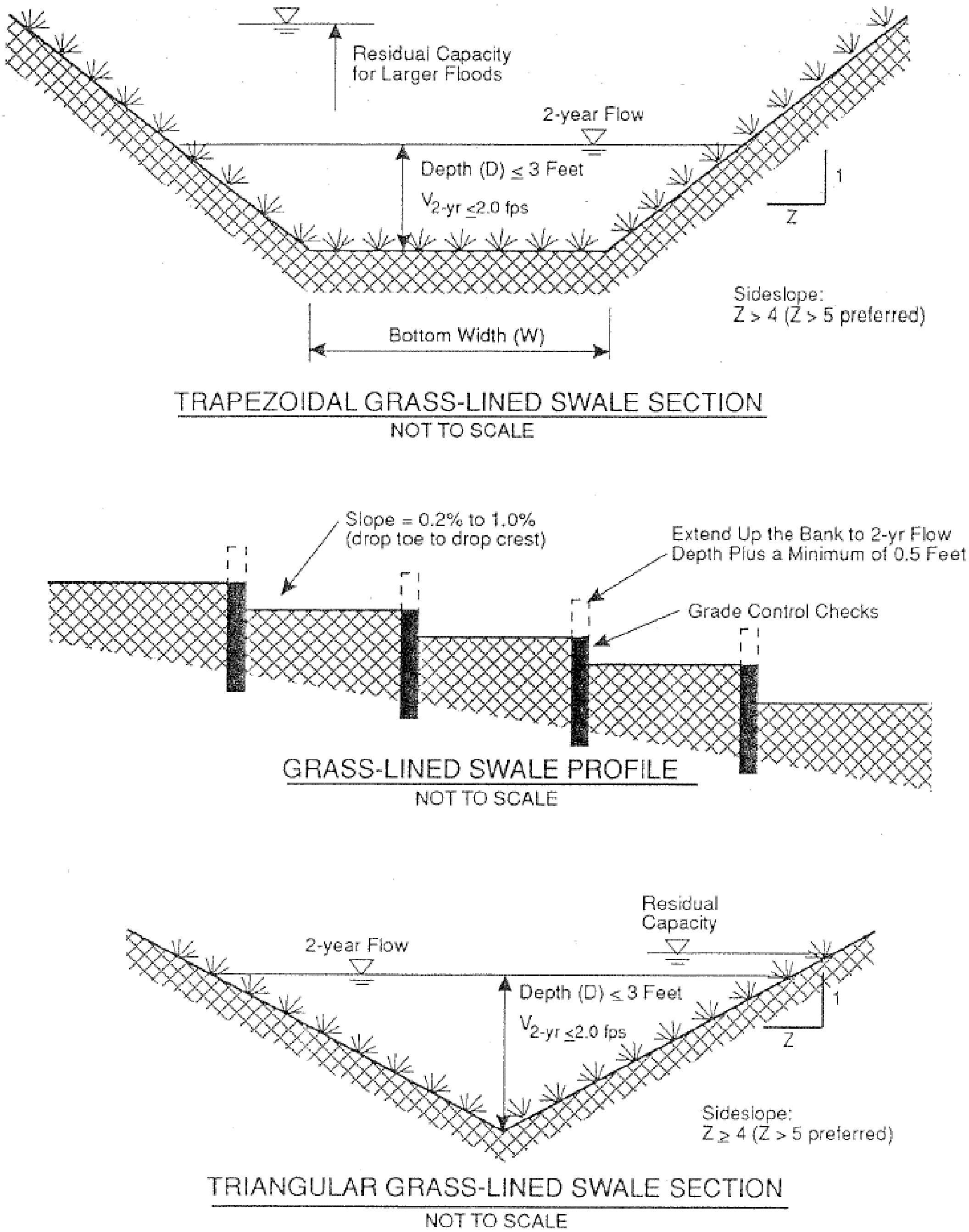


Figure 8-9 Profile and Sections of a Grassed-Lined Swale

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.5 Filter Strips And Flow Spreaders

Filter strips are vegetated areas designed to accept sheet flow provided by flow spreaders which accept flow from an upstream development. Vegetation may take the form of grasses, meadows, forests, etc. The primary mechanisms for pollutant removal are filtration, infiltration, and settling.

General applicability and experience with technique elsewhere

a. Typical Applications
- Filter strips can be used in residential and commercial sites, adjacent to impervious areas. Effectiveness depends on evenly distributed sheet flow, and limited drainage area and runoff volume. For grass filter strips, the environment must support turf-forming grasses. They have limited effectiveness in pollutant removal, and follow-up structural BMPs will still be required.

b. Design Considerations (See Figure 8-10 for representative schematic)
- The proper function of the flow spreader is key to the performance of the filter strip. If flow is allowed to concentrate, the bulk of the filter strip will be ineffective for pollutant removal and flow reduction. This will also result in erosion over time.
- Flow spreaders and filter strips should be limited to drainage areas of 5 acres or less.
- Channel grade for the last 20 feet of the dike or diversion entering the level spreader should be less than or equal to 1% and designed to provide a smooth transition into spreader.
- Grade of level spreader should be 0%.
- Depth of level spreader as measured from the lip should be at least 6 inches.
- Recommended length, width, and depth of flow spreader are presented in the following table:

Design Flow (cfs)	Entrance Width (ft)	Depth (ft)	End Width (ft)	Length (ft)
0 - 10	10	0.5	3	10
10 - 20	16	0.6	3	20
20 - 30	24	0.7	3	30

- Level spreader lip should be constructed on undisturbed soil (not fill material) to uniform height and zero grade over length of the spreader.
- Released runoff to outlet onto undisturbed stabilized areas in sheet flow and not allowed to reconcentrate below the structure.
- Slope (S_o) of filter strip from level spreader should not exceed 10 percent.
- The design width of the filter strip (W_G) should be the greater of the following: $W_G \geq 10$ feet or $W_G \geq 0.2L_I$, where L_I is the length of flow path of the sheet flow over the upstream impervious surface.
- Spreader lip to be protected with erosion resistant material, such as fiberglass matting or a rigid non-erodible material for higher flows, to prevent erosion and allow vegetation to be established.
- Wooded filter strips are preferred to gravel strips.

c. Other Experiences with BMP
- A Maryland study (Galli, 1992) of six grass filter systems showed that all filters were showing deterioration and decreased performance 1.3 to 2.6 years after installation. Low grass height was cited as the primary cause of decreased performance; the recommendation was that grass should be left as high as possible between mowings. Also, the invasion of annual grasses and weeds that experience seasonal die-back can greatly reduce filtering performance. It was concluded that all filters would fail within three years due to erosion from high runoff rates unless substantial repairs were made.

Reported pollutant removal efficiencies

- Filter strips must accept stormwater runoff as overland sheet flow in order to effectively filter suspended materials out of the overland flow.
- The removal of soluble pollutants is low because the degree of infiltration provided is generally very small.
- Removals of nutrients and oxygen demand decrease as the amount of clay in the soil increases.
- Reported data

20-Foot Wide Grassed Filter Strip (Taken from Schueler, 1987):

Pollutant	Removal Rate (%)
Total Phosphorus	10
Lead	30
BOD	10
Sediment	30
Total Nitrogen	10
COD	10
Copper	30
Zinc	30

100-Foot Wide Grassed Filter Strip (Taken from Schueler, 1987):

Pollutant	Removal Rate (%)
Total Phosphorus	50
Lead	90
BOD	70
Sediment	90
Total Nitrogen	50
COD	70
Copper	90
Zinc	90

Advantages

- Aesthetics of open, green space.
- Low cost, since developments are typically required to have open space in their plans
- Grasses and shrubs or trees provide wildlife habitat.

Disadvantages

a. Human Risk, Public Safety and Potential Liability
- Minimal

b. Environmental Risk and Implications
- The primary flood-control mechanism is infiltration; in areas of high ground water vulnerability, this may not be a good option.

c. Other
- On unstable slopes, soils or vegetation, rills and gullies may develop that negate the usefulness of the strips.
- Excessive pedestrian or vehicle traffic may damage the vegetation and soils structure. The planting of shrubs and trees can help eliminate both of these disadvantages.
- Inadequate maintenance of vegetation may result in partially denuded soils with predictable results in erosion, runoff quality and volume.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
- The key is proper design and maintenance.

b. Routine and Non-routine Maintenance
- Routine maintenance consists of standard turf maintenance.
- Non-routine maintenance consists of turf replacement, soils replacement, and regrading.

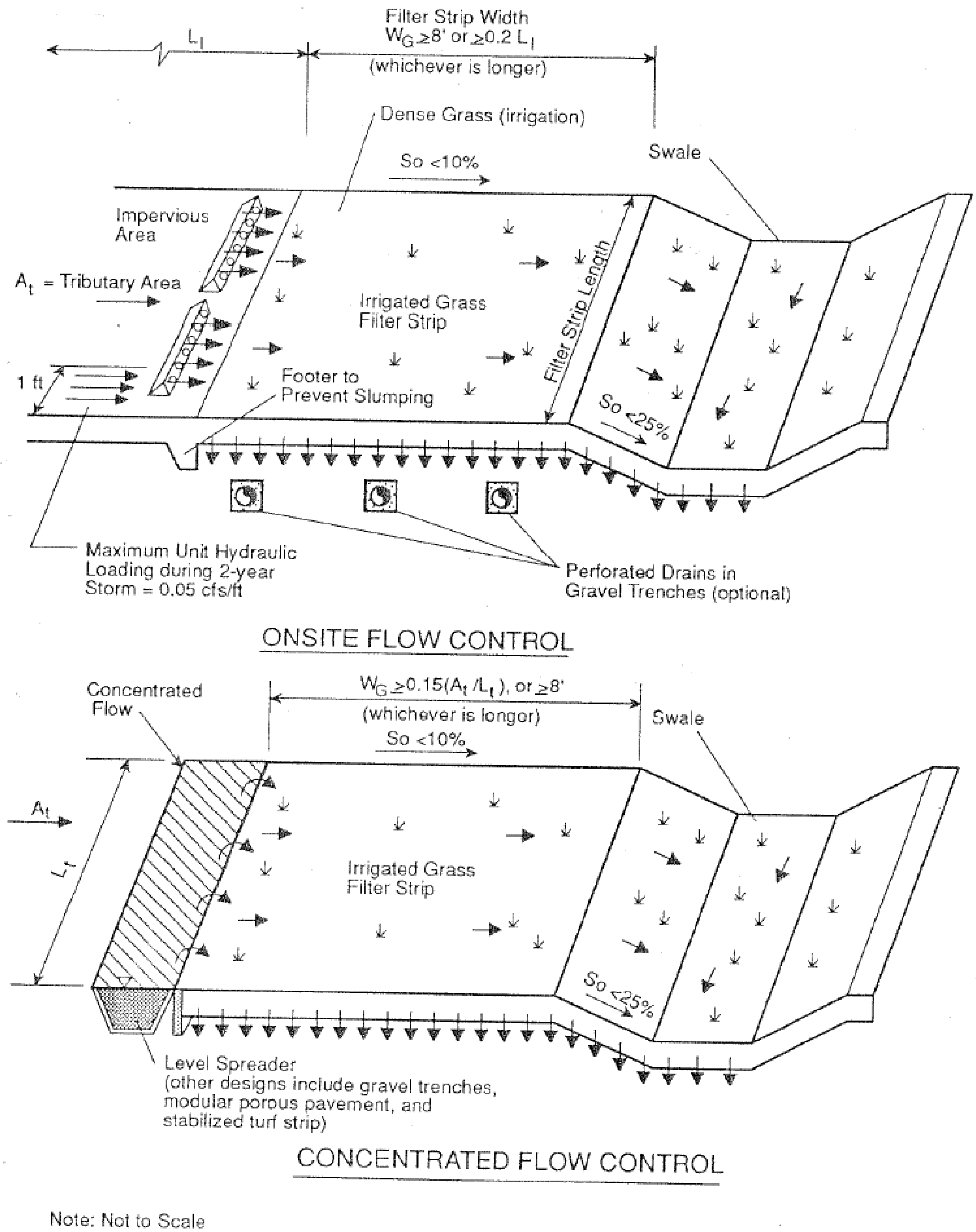


Figure 8-10 Onsite and Offsite Applications of Grass Filter Strips

Source: Denver Urban Drainage and Flood Control District, 1992

8.3.4.6 Sand Filters

In its simplest form, a sand filter is a self-contained bed of sand into which the first flush of runoff is diverted. The water is filtered as it passes through the sand, much like a slow sand filtration system for drinking water supply. The effluent is typically collected with perforated pipe and discharged to a stream or channel.

Sand filters are often placed at the outlet of detention basins to improve effluent water quality. Enhanced sand filters use layers of peat, limestone, and/or topsoil to improve removal rates. Sand trench systems are used to treat parking lot runoff, and these include the Austin sand filter and the Shaver design.

A new modification of the sand filter concept is the biofiltration pond. Using a media which has a cation exchange capacity of at least 10 milli-equivalents per 100 grams will improve metals capture (WEI, 1994). Although sand is still the predominant media of choice, clays and other compounds may be included to attain high pollutant removal rates while still providing ample drainage for the design storm event. This can typically be accomplished using a gradation of filter media, decreasing in size with depth.

<u>General applicability and experience with technique elsewhere</u>

a. Typical Applications
- Sand filters have been successfully used in diverse applications for small (less than 10 acres) tributary areas (Debo, 1994).
- Recommended for "ultra-urban" areas where area is limited and runoff is poor quality; not recommended for new construction sites.
- Most sand filters are limited to an impervious tributary area of 5 to 10 acres. Follow-up sand filters, placed at the outlet of detention basins, may treat tributary areas in excess of 100 acres (Urbonas and Ruzzo, 1986).

b. Design Considerations (See Figure 8-11 for representative schematic)
- Inlet structure should be designed to spread the flow uniformly across the surface of the filter media.
- Riprap or other dissipation devices should be installed to prevent gouging of the sand media and to promote uniform flow.
- Final sand bed depth should be at least 18 inches.
- Underdrain pipes should consist of main collector pipes and perforated lateral branch pipes.
- The underdrain piping should be reinforced to withstand the weight of the overburden.
- Internal diameters of lateral branch pipes should be 4 inches or greater and perforations should be 3/8 inch.
- Maximum spacing between rows of perforations should not exceed 6 inches.
- All piping should be schedule 40 polyvinyl chloride or greater strength.
- Minimum grade of piping should be 1% slope.
- Access for cleaning all underdrain piping should be provided.
- A presettling basin and/or biofiltration swale is recommended to pretreat runoff discharging to the sand filter.
- A maximum spacing of 10 feet between lateral underdrain pipes is recommended.
- The primary purpose of the sand filter is to improve stormwater quality; they have a limited ability to reduce peak flows.
- The retrofitting of sand filters has been performed in several applications (Schueler et al. 1992).

c. Other Experiences with BMP
- Of the nearly 1000 sand filters installed since the early '80s in the Austin, Texas area, the vast majority are working to design specifications and very few have failed (Schueler et al., 1992)

Reported pollutant removal efficiencies

- Reported data:

Pollutant	Removal Rate (%)
Total Phosphorus	65
Lead	50-70
BOD	60
Sediment	85
Total Nitrogen	50
Zinc	60-80
COD	80
Bacteria	50-60

- Sand/peat beds have higher removal effectiveness due to adsorptive properties of peat.
- Designs incorporating vegetative cover on the filter bed increase nutrient removal.
- Pretreatment (sedimentation or oil and grease removal) will enhance the performance of the filter and will decrease the maintenance frequency required to maintain effective performance.
- The sand filter does not rely on infiltration to remove peak stormwater flows or improve effluent quality. At the same time it does appear to have good removal rates of most pollutants (with the possible exception of nitrogen), with the potential to increase removal efficiencies through the addition of other media such as peat, clays, limestone, and grass cover. The use of sand with high iron content also may improve efficiencies.

Advantages

- Since infiltration is not a significant mechanism, ground water protection is maximized.
- This BMP has a proven performance record in a variety of applications.

Disadvantages

a. Human Risk, Public Safety and Potential Liability
  - Basin should be grated to prevent unauthorized entry.

b. Environmental Risk and Implications
  - Since the removed sand has been demonstrated to be non-toxic, and there is no evidence that resuspension of contaminated sediment is a problem, there is little concern for environmental problems with this BMP.

c. Other
  - Larger sand filters with no vegetative cover may be unattractive; the surface can be extremely unattractive and some have caused odor problems.
  - Sand filters are primarily for stormwater quality mitigation, not quantity or peak flow mitigation.

Maintenance/monitoring/enforcement considerations

a. Routine and Non-routine Maintenance
  - The primary routine maintenance is debris removal and scraping of the upper sand layer. This is mostly manual work.
  - Non-routine maintenance includes resanding (replacement of the sand) after enough sand has been removed that significant breakthrough occurs. In the case of the Shaver design in which a sedimentation basin is included, this must be cleaned out when the basin loses its holding capacity.

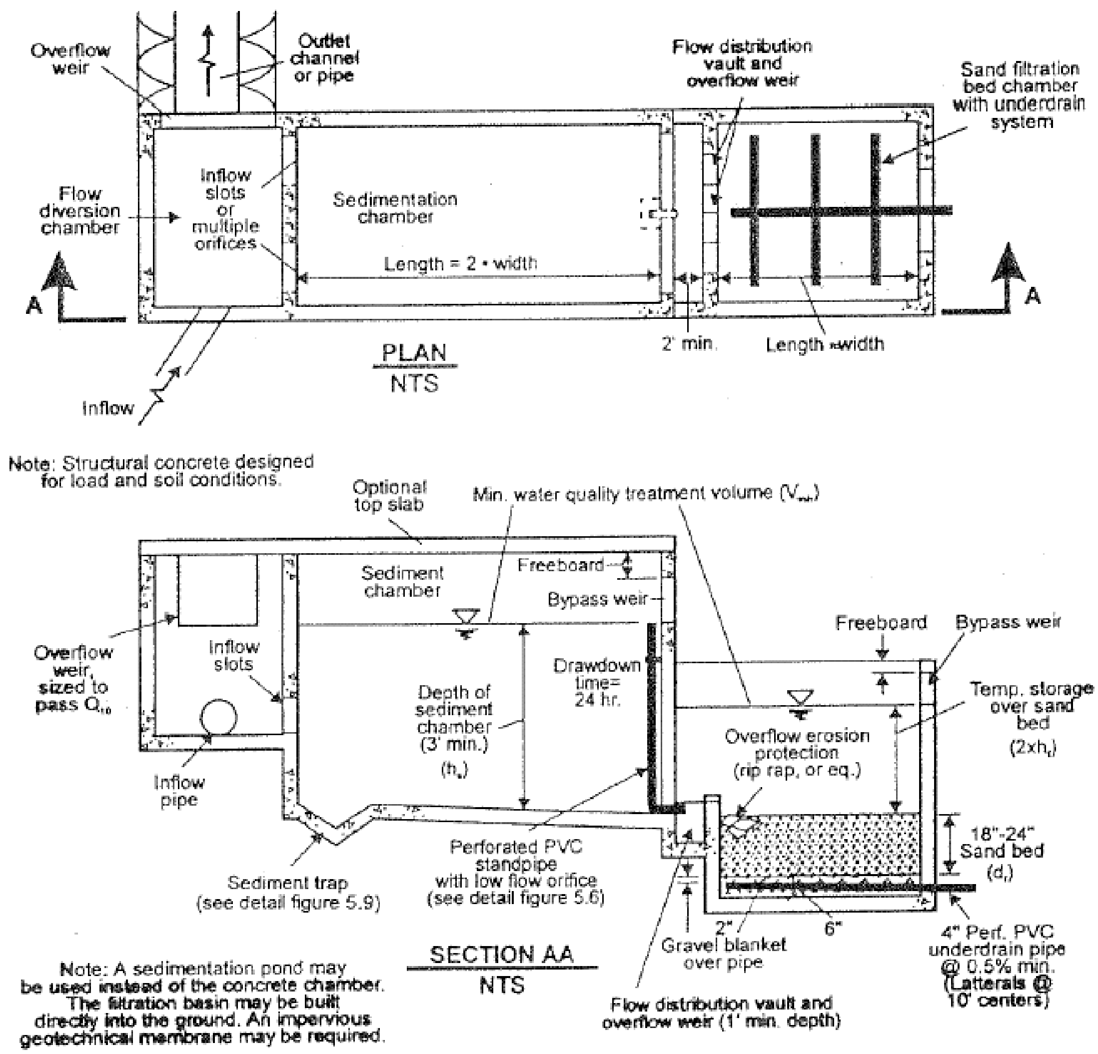


Figure 8-11 Sand Filtration Basin

Source: Center for Watershed Protection, 1996

8.3.4.7 Infiltration Trenches

Infiltration trenches can be generally described as a part of an open ditch that encourages rapid infiltration of runoff to the ground water through the placement of materials with high hydraulic conductivities. The trench is basically an excavated area within the ditch into which clean gravels are placed. The ditch should provide for slow flow rates to allow settling of suspended solids as well as the opportunity for substantial infiltration of the total intercepted flow.

General applicability and experience with technique elsewhere

a. Typical Applications
- As an infiltration type BMP, use should be limited to those areas where ground water levels are well below the bottom of the trench and there is significant retention time in the soils before reaching ground water.
- Commonly, infiltration trenches are sized to intercept and dispose of runoff from a specific design storm (typically 2-year storms).

b. Design Considerations (See Figure 8-12 for representative schematic)
- Use in drainage areas less than 15 acres.
- Soils that are suitable for infiltration systems are silt loam, loam, sandy loam, loamy sand, and sand.
- Soils that have a 30 percent or greater clay content are not suitable for infiltration trenches.
- The soil infiltration rate should be between 0.5 and 2.4 inches per hour.
- The use of infiltration systems on fill is not allowed due to the possibility of creating an unstable subgrade.
- A minimum of 3 feet between the bottom of the infiltration trench and the groundwater table is recommended.
- Site slope should be less than 20 percent and trench should be horizontal.
- The proximity of building foundations should be at least 10 feet upgrade.
- A minimum of 100 feet should be maintained from water supply wells when the runoff is from industrial or commercial areas.
- Water quality infiltration trenches should be preceded by a pretreatment BMP.
- The aggregate material for the trench should consist of a clean aggregate with a maximum diameter of 3 inches and a minimum diameter of 1.5 inches.
- The aggregate should be graded such that there will be few aggregates smaller than the selected size. For design purposes, void space for these aggregates may be assumed to be in the range of 30 percent to 40 percent.
- The aggregate should be completely surrounded with an engineering filter fabric. If the trench has an aggregate surface, filter fabric should surround all aggregate fill material except for the top one foot.
- Bypass larger flows.
- To reduce clogging of the trench with sediments, a sump pit or a filter strip and flow spreader should be used to treat water entering the ditch.
- Since infiltration is the primary mechanism for pollutant removal from runoff, the infiltration trench could actually impair ground water quality in fast-draining soils. Some biological uptake of nutrients may occur in well-vegetated ditches, and removal of sediments will remove some associated heavy metals.
- The most important aspect to the potential for success of an infiltration trench is ground water levels. If the trench is easily inundated by high ground water levels or ground water mounding due to infiltration of runoff, the trench will simply become an open channel. Thus, the trench can fail in two modes; high infiltration rates to ground water that is near the base of the trench, or low infiltration rates due to poor draining soils or clogging of the trench with sediments.
- Infiltration trenches work well for residential lots, commercial areas, parking lots, and open space areas.
- Infiltration systems should not be constructed until all construction areas draining to them are fully stabilized.

- An analysis should be made to determine any possible adverse effects of seepage zones when there are nearby building foundations, basements, roads, parking lots, or sloping sites.

c. Other Experiences with BMP
- In a Maryland study (Galli, 1992) of 38 infiltration trenches, losses of infiltration capacity were caused by high water tables, poorly draining soils, and inadequately sized filter strips.
- As mentioned previously, the term 'infiltration trench' implies that runoff water is intercepted and directed to the ground water. Unless other BMPs are included to remove pollutants before the runoff enters the trench, ground water quality may be compromised. However, Urbonas and Stahre (1993) state that data available so far shows that ground water quality does not degrade noticeably due to infiltration of stormwater from residential and many types of commercial developments. Filtration, adsorption, and ion exchange may occur in the underlying soils.

<u>Reported pollutant removal efficiencies</u>

- Removal rates have been estimated by Schueler (1987) using assumed efficiencies and modeling. These show very high removal rates for TSS, Nitrogen, Phosphorous, Zinc and BOD.

<u>Advantages</u>

- The combination of water conveyance, runoff reduction, lowering of peak flows, and pollutant removal make this an effective BMP.

<u>Disadvantages</u>

a. Human Risk, Public Safety and Potential Liability
- Minimal

b. Environmental Risk and Implications
- The use of infiltration as the primary pollutant reduction mechanism may increase ground water contamination by highly soluble contaminants in fast-draining soils and/or high water level conditions.

c. Other
- If a trench becomes clogged with sediments, it simply stops functioning. The gravel must be removed and replaced with clean gravel, and it may be necessary to remove soils lining the trench which have also become clogged. The Maryland study (Galli, 1992) gave the following results for 38 trenches averaging 2.4 years old (maximum 5.1 years):

	Operating as designed?		
Pre-treatment type	Yes	No	Unknown
Sump Pit	48.4%	42.0%	9.6%
Grass Filter	42.9%	57.1%	0.0%
TOTAL	47.4%	44.7%	7.9%

- Conversely, a state survey of infiltration devices in Maryland in 1986 showed 80% of the infiltration trenches working as designed (Clement and Pensyl, 1987). These results are questionable, however, as 50% of the trenches had no observation wells to determine if there was standing water under the gravel. Such trenches were reported as operating properly even though this primary evaluation criteria could not be determined.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
- If non-routine maintenance is performed correctly, there should be little degradation in performance

b. Routine and Non-routine Maintenance
- Routine maintenance includes debris and litter removal and control of overgrown vegetation.
- Non-routine maintenance involves a clogged trench which requires complete removal and replacement of the gravel as well as surrounding clogged native soils. This can be greatly reduced by proper design and routine maintenance.

c. Sustainability of Maintenance or Program Management
- If the trench becomes fully clogged, complete rehabilitation may cost as much as initial construction; if funding is private, the trench may go unrepaired.

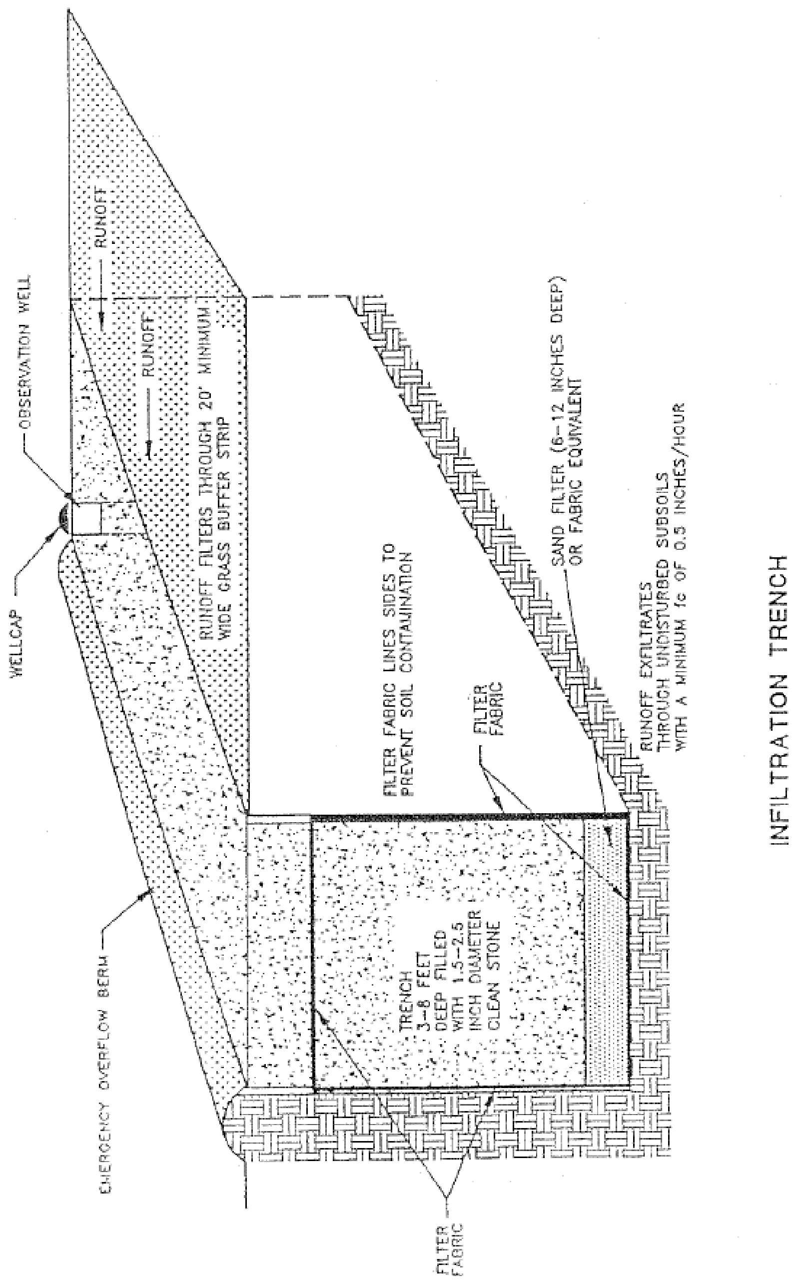


Figure 8-12 Infiltration Trench

Source: Stormwater Management Manual For The Puget Sound Basin

8.3.4.8 Porous Pavement

There are two forms of porous pavement: modular block, which is made porous through its structure, and poured-in-place concrete or asphalt which is porous due to the mix of the materials.

Modular block porous pavement consists of perforated concrete slab units underlain with gravel. The surface perforations are filled with coarse sand or sandy turf. It is used in low traffic areas to accommodate vehicles while facilitating stormwater runoff at the source. It should be placed in a concrete grid that restricts horizontal movement of infiltrated water through the underlying gravels.

Poured-in-place porous concrete or asphalt is generally placed over a substantial layer of granular base (Urbonas and Stahre, 1993). The pavement is similar to conventional materials, except for the elimination of sand and fines from the mix.

If infiltration to ground water is not desired, a liner may be used along with perforated pipe and a flow regulator to slowly drain the water away over a 6 to 12 hour period.

<u>General applicability and experience with technique elsewhere</u>

a. Typical Applications

- This is exclusively an on-site BMP that should never be used for treating water with high sediment loads. This is particularly true for porous concrete or asphalt, which are primarily designed to remove pollutants deposited on the pavements from the atmosphere (Schueler, 1987)
- Modular block pavement is applicable to low traffic zones and permeable upper soils with ground water no less than 4 feet from the gravel bedding.
- The use of porous concrete or asphalt is not well-received in colder climates where freeze-thaw cycles may fracture the pavement. Despite this, it has been found that properly designed systems are not damaged by such processes (Debo, 1994).

b. Design Considerations (See Figures 8-13 and 8-14 for representative schematics)

- Either form of porous pavement must be limited to low traffic areas with limited deposition of clays and fines which could clog the pavement.
- As infiltration is the primary mechanism of pollutant removal, areas with high ground water vulnerability may not be good choices for this BMP.
- Large soil surface areas are needed for maximum exfiltration and pollutant removal.
- Soil infiltration rate should be greater than 0.27 inches per hour and clay content less than 30 percent.
- Only feasible on sites with gentle slopes (less than 5%).
- Design infiltration rate should be equal to ½ of the infiltration rate determined from soil textural analysis.
- Minimum of 3 feet between stone reservoir level and seasonally high water table.
- Should not be constructed over fill soils.
- Vegetative strip or diversion berm required to protect pavement area from off-site runoff before, during, and after construction.
- If porous pavement areas receive runoff from off-site areas, a pretreatment facility should be constructed to remove oil, grit, and sediments before entering the porous pavement.
- Dry subgrade should be covered with engineering filter fabric such as Mirafi #14N or equal on bottom and sides.
- Pavement section consisting of 4 layers as shown on Figure 8-9.
- Stone should be clean, washed, stone meeting roadway standards.
- Reservoir base course should consist of 1" to 3" crushed stone aggregate compacted lightly at the depth required to achieve design storage.
- Filter courses to be ½" crushed stone aggregate at a 1" to 2" depth.
- Surface course should be laid in 1 lift at the design depth with compaction done while the surface is cool enough to resist a 10-ton roller. Only 1 or 2 passes are required.

- After final rolling, no vehicular traffic should be permitted on pavement until cooling and hardening, a minimum of 1 day.
- Stone reservoir should be designed to completely drain within a maximum of 2 to 3 days after design storm event.
- The porous pavement site should be posted with signs indicating the nature of the surface and warning against resurfacing, using abrasive, and parking heavy equipment.
- An observation well should be installed on the downslope end of the porous pavement area to monitor runoff clearance rates. The observation well should consist of perforated PVC pipe, 4 to 6 inches in diameter, constructed flush with the ground. The top of the observation well should be capped to discourage vandalism and tampering.
- Limited in application to parking lots, service roads, emergency and utility access lanes, and other low traffic areas.
- Limited to sites between 1/4 acre and 10 acres.
- Should not be constructed near groundwater drinking supplies.
- Heavy equipment should be prevented from compacting the underlying soils before and during construction.

c. Other Experiences with BMP

- Modular block BMPs have been in use since the mid-1970's. Field data is lacking to quantify long-term performance as an infiltration device, but anecdotal evidence indicates it is reliable. Pratt (1990) found that if excessive sediment deposition is controlled, modular paved surfaces can function for at least 15 years.
- Anecdotal experience indicates that unless careful cleaning with vacuum cleaners is performed on a frequent basis, the pavement will seal within 1-3 years. Ultimately, it will seal anyway and cannot be repaired; the only option appears to be replacement. (Urbonas and Stahre, 1993). Porous pavement sites have one of the highest failure rates of any BMP. At the same time, when working properly it can be a very cost-effective BMP for commercial sites.
- As infiltration is a primary mechanism, the potential for pollutant discharge to ground water, particularly soluble pollutants, is significant. Additionally, there is concern that hydrocarbons may be leached from asphalt material, thereby increasing the contaminant load.

Reported pollutant removal efficiencies

- Reported data

  Representative long-term pollutant removal rate for porous pavement sites designed for the 2-year storm are as follows (Debo, 1995):

Pollutant	Removal Rate (%)
Total Phosphorus	65
Lead	98
Sediment	95
Total Nitrogen	85
COD	82
Zinc	99

- Suspended sediment and associated metals, oil and grease removal may be high, as long as the pavement remains porous. Removal rates estimates vary from 0 to 95 percent. Soluble constituent removal is likely lower, depending on the materials used. Filtration, adsorption, and ion exchange may occur in the underlying soils. With good drainage, soluble constituents are likely to show low removal efficiencies (UDFCD, 1992).

Advantages

- Low maintenance for modular block pavement.
- Slows and reduces runoff, reducing the need for expensive detention facilities.

Disadvantages

a. Environmental Risk and Implications
- Fast draining soils can encourage ground water pollution from soluble metals and other pollutants.
- Risk can vary from very minor to great, depending on how well the system is functioning

b. Other
- Large silt and sand loads (e.g. from construction sites) may accelerate the clogging of the pavement pores, requiring expensive removal of sediments.
- Porous concrete or asphalt tends to seal in 1-3 years unless vacuum cleaning is done frequently; even then, it will eventually seal. The need for vacuum cleaning makes this option more expensive for routine maintenance.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
- All porous pavement designs will degrade in performance over time, with careful maintenance only incrementally increasing its operational lifespan.

b. Routine and Non-routine Maintenance
- Maintenance is minimal for modular block except when the surface becomes clogged. This will require expensive non-routine maintenance in the form of removing the blocks and the underlying clogged gravels. Routine (quarterly) vacuum sweeping and high pressure water washing of porous asphalt is required to prevent clogging. Non-routine maintenance consists of complete replacement, and may be required in as little as one year's time.
- When turf is used with modular block, lawn care maintenance is needed.
- Sand or ash should not be applied to porous pavement.
- Spot clogging of the porous pavement layer can be relieved by drilling 1/4" holes through the porous asphalt layer every few feet.

c. Sustainability of Maintenance or Program Management
- The obvious limitation is the need for expensive non-routine repairs or replacement. If privately owned, this expense may preclude necessary work. If publicly owned, there may be insufficient funds budgeted for maintenance.

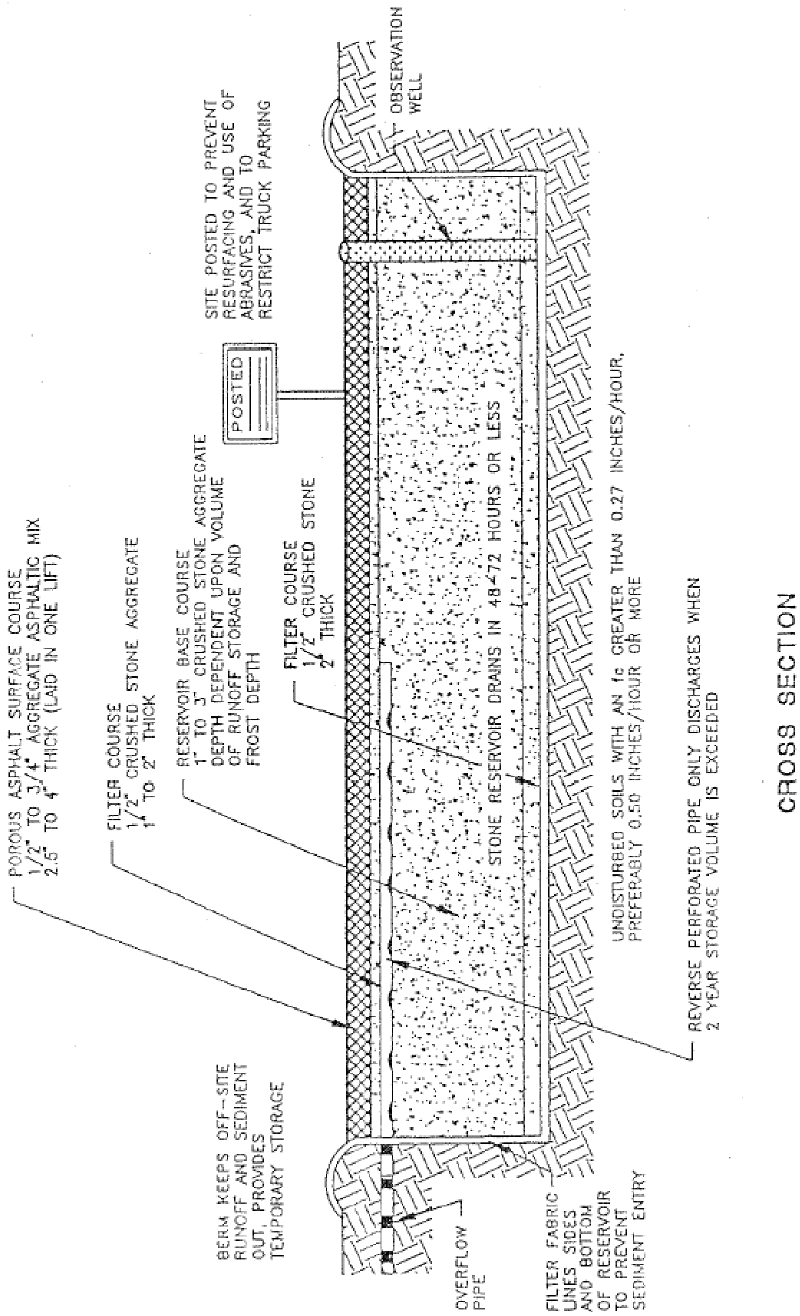
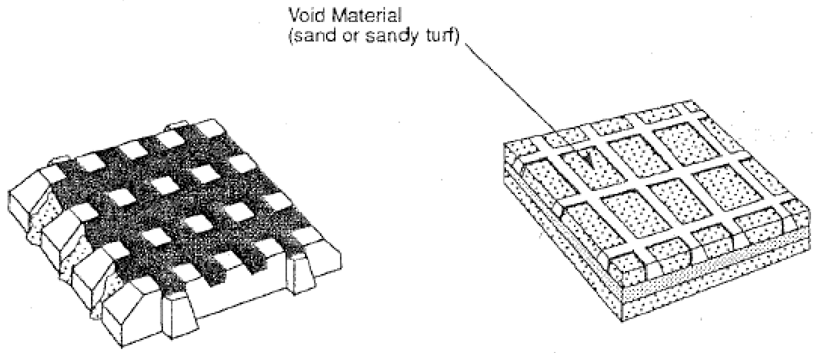
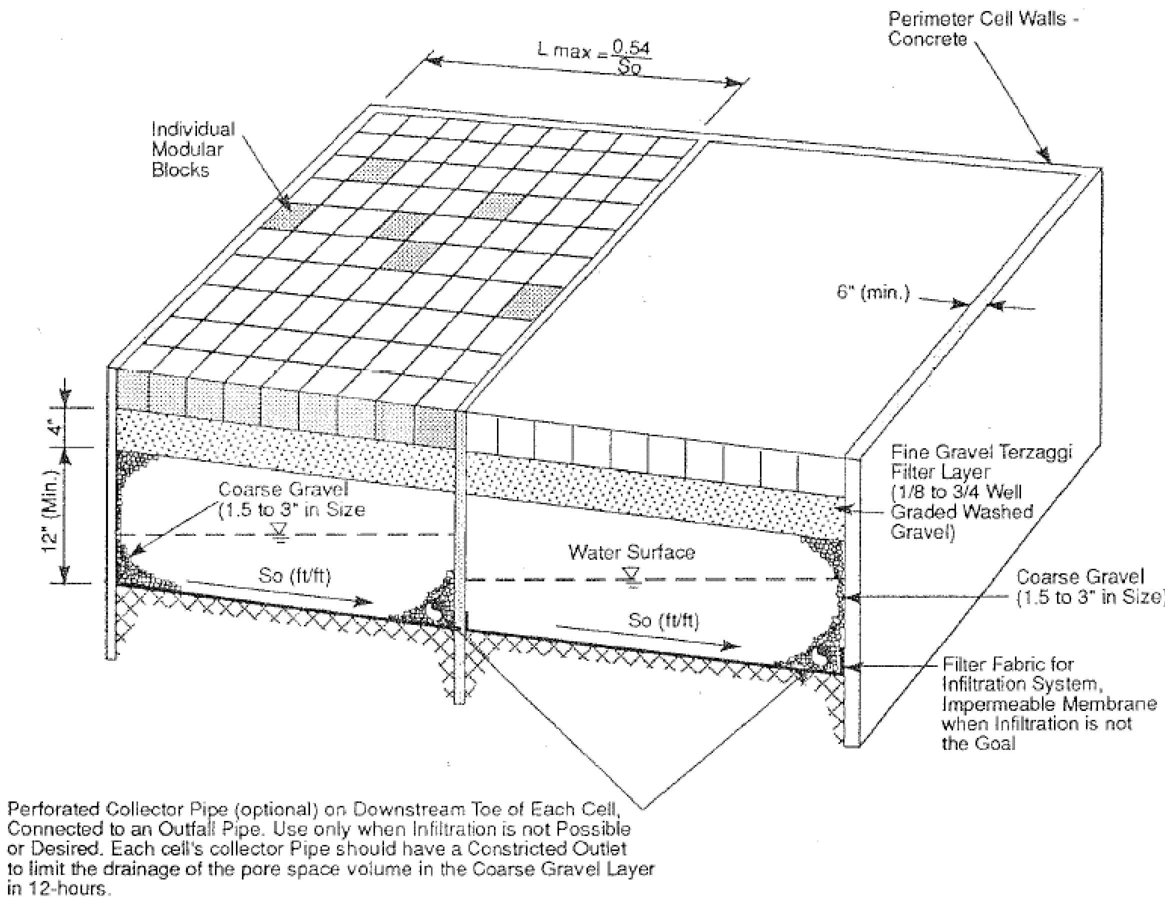


Figure 8-13 Design Schematic For Porous Pavement

Source: Controlling Urban Runoff



TWO EXAMPLES OF INDIVIDUAL CONCRETE MODULAR PAVING BLOCK



PERSPECTIVE OF SIDE-BY-SIDE MODULAR BLOCK CELLS

Figure 8-14 Design Schematic For Modular Block Porous Pavement

Source: Urban Drainage and Flood Control District, 1992

8.3.4.9 Oil/Grit Separators

Also known as a water quality inlet, an oil and grit separator is a three-stage underground retention system designed to remove heavy particulates and hydrocarbons from runoff. The first chamber allows for sedimentation. The second chamber has an inverted elbow for an outlet, such that oil is trapped at the surface. The third chamber directs the water out.

<u>General applicability and experience with technique elsewhere</u>

a. Typical Applications
- This BMP was originally designed for industrial applications, rater than urban storm water applications. When translating to a storm water BMP, two problems arise: (1) an expectation of removal of pollutants other than oil and grit is created; and (2) widely varied flows can overwhelm and make ineffective a BMP that was designed for steady low flows and not "flashy" high flows.
- The most effective use of this BMP is in capturing runoff from small, high density sites where high concentrations of oils in runoff are expected.
- Oil/Grit separators are most frequently used in highly urbanized areas where other BMPs cannot be used due to space limitations.

b. Design Considerations (See Figure 8-15 for representative schematic)
- Tributary area is usually limited to two acres or less of mostly impervious surfaces. This is primarily a water quality rather than quantity mitigation BMP.
- Separator should be structurally sound and designed for acceptable traffic loadings where subject to traffic loadings.
- Separator should be designed to be water tight.
- Volume of separator should be at least 400 cubic feet per acre tributary to the facility (first two chambers).
- Forebay or first chamber should be designed to collect floatables and larger settleable solids. Its surface area should not be less than 20 square feet per 10,000 square feet of drainage area.
- Oil absorbent pads, oil skimmers, or other approved methods for removing accumulated oil should be provided.
- Separator pool should be at least 4 feet deep.
- Manholes should be provided to each chamber to provide access for cleaning.
- Separator to be located close to the source before pollutants are conveyed to storm sewers or other BMPs.
- Use only on sites of less than one acre.
- Provide perforated covers as trash racks on orifices leading from first to second chamber.

c. Other Experiences with BMP
- Experience demonstrates that these have limited pollutant removal ability with resuspension of trapped particulates common. Since residues tend to be toxic, disposal is a problem. As a result, there are no current clean-out and disposal procedures.

<u>Reported pollutant removal efficiencies</u>

- Pollutant removal ability is limited. This is due to the lack of clean-out and disposal procedures and the tendency for trapped sediments to resuspend. One study (Shepp et al. 1992) showed that the depth of trapped sediments in over 120 separators was less than two inches. More than eighty percent of the sediments were coarse-grained grit and organic matter. Additionally, the amount of trapped sediment did not correlate with age, indicating that resuspension is a common failure mode. Sediments that were trapped were very oily in nature.
- The positive aspect to this BMP is that examination of the sediments shows that the adsorbed pollutants match those found in receiving water bodies, indicating that the right target pollutants are being addressed.

- Three chamber oil and grit devices may remove from 60 to 80 percent of the hydrocarbons found in parking lot and street runoff.
- Three chamber oil and grit devices may also remove a small portion of the suspended sediment and trace metal loads.

Advantages

- Can be used in highly urbanized areas where other BMPs cannot be used.
- Trapping of floatable trash and debris and possible reduction of hydrocarbon loadings from impervious areas.
- They do not rely on infiltration, so that direct input of runoff into the ground water is unlikely.

Disadvantages

a. Human Risk, Public Safety and Potential Liability
   - The trapped sediments are highly toxic (organics)

b. Environmental Risk and Implications
   - Trapped sediments are highly toxic and cannot be easily disposed of, resulting in the generation of a toxic waste.
   - Large storm events can cause resuspension of trapped solids, resulting in a pulse of very poor quality effluent.

c. Other
   - The lack of a practical disposal method for the toxic sediments results in improper maintenance that causes failure of the system.

Maintenance/monitoring/enforcement considerations

a. Reliability and Consistency over Time
   - Pollutant removal performance likely drops off very quickly after a few months.

b. Routine and Non-routine Maintenance
   - Sediments are toxic and cannot be landfilled; therefore, maintenance involves only the removal of floatables.
   - Cleaning on a quarterly basis should be a minimum schedule with more intense land uses such as gas stations requiring cleaning as often as monthly.
   - Cleaning should include pumping out waste water and grit and having the water processed to remove oils and metals.

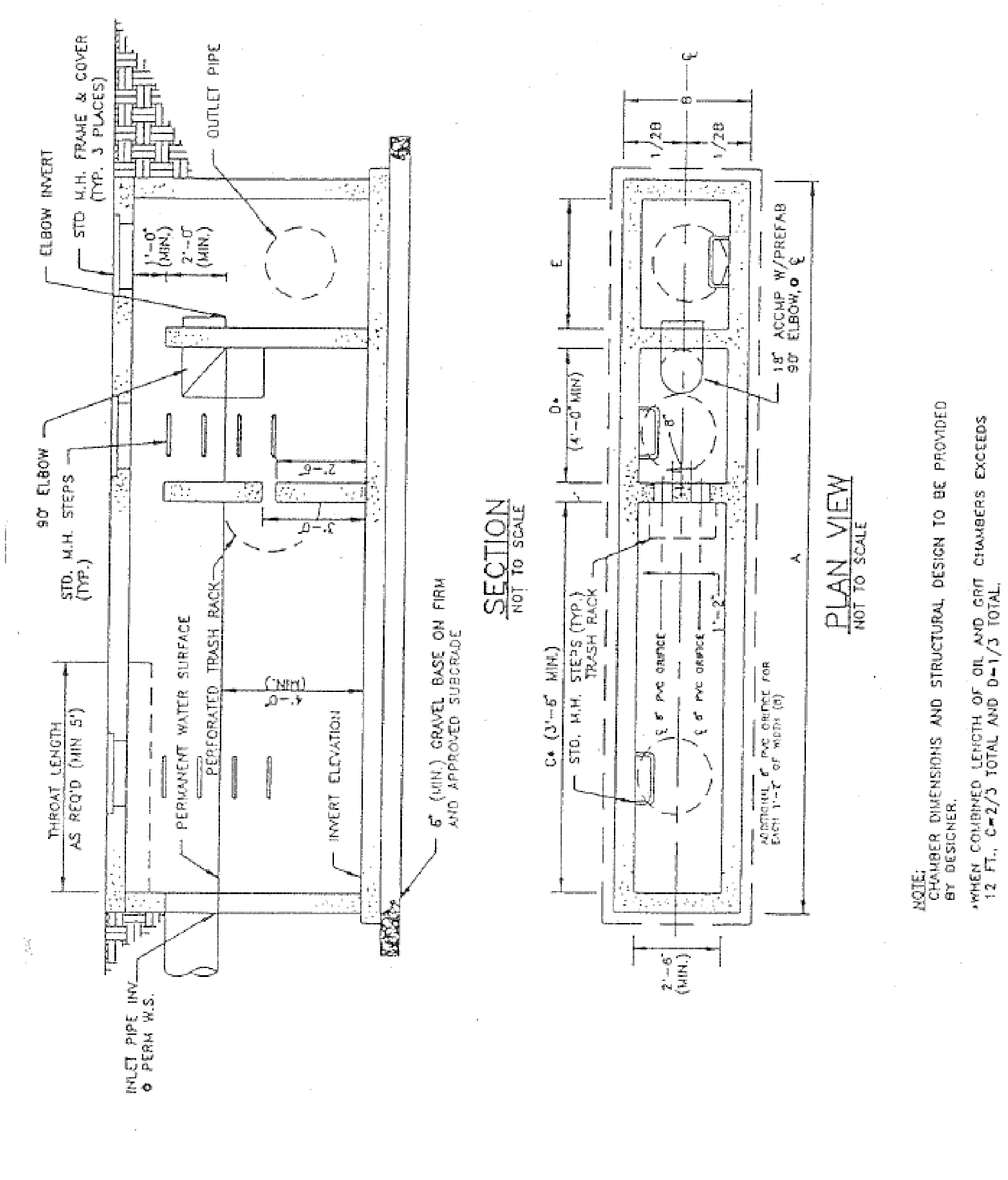


Figure 8-15 Oil/Grit Separator

Source: Maryland Department Of The Environment Sediment And Stormwater Administration

8.3.4.10 Grate Inlet Inserts

Grate inlet inserts are a newer type of oil/grit separator consisting of an insert that fits inside a standard grate inlet. Normally the inserts are made of a stainless steel, aluminum or cast iron framework which sits on the lip of the inlet grate frame and hangs down into the catch basin inlet chamber. One or more trays of filtration media are placed into the framework. The top screen or tray is usually a sediment trap. The flow enters the top of the filtration tray and filters through. Filtering media can be made of activated charcoal (for pesticides, fertilizer and metals removal), reconstituted wood fiber (primarily for oil and grease) or household fiberglass insulation. Excess flow beyond the capacity of the media bed or due to media clogging is routed over the sides of the tray(s) and out through the bottom or side of the framework. The capacity of the overflow is designed to equal or exceed the capacity of the grate.

One or more trays of filtering media, sometimes of different types, are then placed either stacked or in a rack below the sediment trap and screen. The media can be disposed in a manner similar to oil and grit chamber sediment though it may need to be tested once to see if it is a hazardous waste.

<u>General applicability and experience with technique elsewhere</u>

a. Typical Applications
- These can be used in most places where catch basins are installed.
- It appears to be an ideal application for retrofitting such areas as parking lots, gas stations, vehicle maintenance areas, "dirty" neighborhoods or industrial areas, etc.

b. Design Considerations
- Several companies produce such inserts, or they can be fabricated from common materials. The materials which make up the framework and the trays should be highly resistant to corrosion, easy to install manually and fit standard inlets.

<u>Reported pollutant removal efficiencies</u>

- Pollutant removal rate information is limited to a few installations, some bench tests and visual inspections. But it appears to be quite high for oil and grease and metals (above 80%-90%) (Debo, 1994).

<u>Advantages</u>

- It is easy to install (may take as little as 15 minutes), relatively inexpensive, requires no construction or modifications of existing catch basins, easy to maintain by property owners, and is targeted toward the major pollutants from these areas.

<u>Disadvantages</u>

a. Human Risk, Public Safety and Potential Liability
- Similar to conventional catch basins

b. Environmental Risk and Implications
- Difficult to quantify, but should be significantly improved over conventional basins.

<u>Maintenance/monitoring/enforcement considerations</u>

a. Reliability and Consistency over Time
- Unknown, but proper maintenance should provide a reasonable lifetime vs. costs. There is some question concerning the chemical integrity and longevity of the fiberglass in harsher environments.

b. Routine and Non-routine Maintenance

- Maintenance requirements include inspecting the flow integrity of the system and replacement of the filtration media. Quarterly replacement is a good starting estimate though the installations should be checked after wet periods and periodically.

c. Sustainability of Maintenance or Program Management
- Routine maintenance is required and must be built into the cost estimate for the system.

8.4 Nonstructural Best Management Practices

Previous sections of this chapter presented the details of structural best management practices and their use within the municipal drainage system. The other major category of BMPs include the many nonstructural or source control practices that can be used for pollution prevention and control of pollutants. In most cases it is much easier and less costly to prevent the pollutants from entering the drainage system than trying to control pollutants with structural BMPs. Thus within the "treatment train" concept, the nonstructural BMPs should be the first line of defense in protecting the receiving stream within the municipality. If used properly, the nonstructural BMPs can be very effective in controlling pollutants and greatly reduce the need for structural BMPs. In addition, nonstructural BMPs tend to be less costly, easier to design and implement and easier to maintain than structural BMPs. The following is a brief discussion of some nonstructural BMPs that can be used in the Lincoln area.

8.4.1 Public Education/Participation

Public education/participation is not so much a best management practice as it is a method by which to implement BMPs. Public education/participation are vital components of many of the individual source control BMPs. A public education and participation plan provides the municipality with a strategy for educating its employees, the public, and businesses about the importance of protecting stormwater from improper use, storage, and disposal of pollutants. It is important that residents become aware that a variety of hazardous products are used in the home and that their improper use and disposal can pollute stormwater and groundwater supplies. Businesses, particularly smaller ones that may not be regulated by Federal, State, or local regulations, must be informed of ways to reduce their potential to pollute stormwater.

The public education and participation plan should be based on four objectives:

- promote a clear identification and understanding of the problem and the solutions,
- identify responsible parties and efforts to date,
- promote community ownership of the problems and the solutions, and
- integrate public feedback into program implementation.

Target audiences include:

- Political - elected officials, chambers of commerce, and heads of departments, agencies, and commissions;
- Technical - municipal department and agency staffs, State agencies;
- Business - commercial and industrial, including trade associations;
- Community Groups - fraternal, ethnic, hobby, horticulture, senior citizen, and service;
- Environmental;
- General Public/Residential;
- Schools/Youth Groups;
- Media - print and electronic, and
- Pollutant-defined - groups of individuals defined by the specific pollutant(s) they discharge (e.g., used motor oil, pesticides)

For these target audiences the activities within the public education/participation plan can include surveys, presentations, school activities, development of working committees, development of literature and media campaigns, workshops, etc. All of these activities can be an important part of controlling local stormwater management problems.

8.4.2 Land Use Planning/Management

This BMP presents an important opportunity to reduce the pollutants in stormwater runoff by using a comprehensive planning process to control or prevent certain land use activities in areas where water quality is sensitive to development. It is applicable to all types of land use and represents one of the most effective pollution prevention practices. Subdivision regulations, zoning ordinances, preliminary plan reviews and detailed plan reviews, are tools that may be used to mitigate stormwater contamination in newly developing areas. Also, master planning, cluster development, terracing and buffers are ways to use land use planning as a BMP in the normal design for subdivisions and other urban developments. These are planning tools that municipal agencies can use to require conditions of approval or establish improvement/construction standards to meet the water quality objectives within specific watersheds.

An impervious cover limitation is one of the more effective land use management tools, since nationwide research has consistently documented increases in pollution loads with increases in impervious cover.

In addition, directly connected impervious areas should be kept to a minimum. This is especially important for large impervious areas such as parking lots and highways and it can also be effective for small impervious areas such as roof drainage. Minimization of impervious cover within a development is encouraged.

8.4.3 Material Use Controls

There are three major BMPs included in this category:

1. Housekeeping Practices
2. Safer Alternative Products
3. Pesticide/Fertilizer Use

In housekeeping practices, the goal is to promote efficient and safe practices such as storage, use, cleanup, and disposal, when handling potentially harmful materials such as fertilizers, pesticides, cleaning solutions, paint products, automotive products, and swimming pool chemicals. Alternatives exist for most product classes including fertilizers, pesticides, cleaning solutions, and automotive and paint products, and thus the use of less harmful products should be encouraged.

Pesticides and fertilizers have become an important component of land use and maintenance for municipalities, commercial land uses and residential land owners. Any usage of pesticides and fertilizers increases the potential for stormwater pollution. BMPs for pesticides and fertilizers include education in their use, control runoff from affected areas, control times when they are used, provide proper disposal areas, etc.

For the general public, public education provides information on such items as stormwater pollution and the beneficial effects of proper disposal on water quality; reading product labels; safer alternative products; safe storage, handling, and disposal of hazardous products; list of local agencies; and emergency phone numbers. This information can be provided through brochures or booklets that can be made available at a variety of places including municipal offices, public information fairs, and places where such products are sold. Education should also be developed for municipal employees and commercial and industrial establishments.

8.4.4 Material Exposure Controls

Material storage control is used to prevent or reduce the discharge of pollutants to stormwater from material delivery and storage by minimizing the storage of hazardous materials onsite, storing materials in a designated area, installing secondary containment, conducting regular inspections, and training employees and subcontractors.

8.4.5 Material Disposal And Recycling

There are three major BMPs included in this category:

1. Storm Drain System Signs
2. Household Hazardous Waste Collection
3. Used Oil Collection

Stenciling of the storm drain system (inlets, catch basins, channels, and creeks) with prohibitive language/graphic icons discourages the illegal dumping of unwanted materials. This is an ongoing effort within the City of Lincoln.

Household hazardous wastes are defined as waste materials which are typically found in homes or similar sources, which exhibit characteristics such as: corrosivity, ignitability, reactivity, and/or toxicity, or are listed as hazardous materials by the EPA.

Used oil recycling is a responsible alternative to improper disposal practices such as dumping oil in the sanitary sewer or storm drain system, applying oil to roads for dust control, placing used oil and filters in the trash for disposal to landfill, or simply pouring used oil on the ground.

Storm drain system signs act as highly visible source controls that are typically stenciled directly adjacent to storm drain inlets. The signs contain brief statements that discourage the dumping of improper materials into the storm drain system. Graphical icons, either illustrating anti-dumping symbols or images of receiving water fauna, are effective supplements to the anti-dumping message. The intent of such a storm drain system stenciling program is to enhance public awareness of the pollutant effect on local receiving waters from stormwater runoff and also to discourage individual's habitual waste disposal actions (e.g., automotive fluids and landscaping wastes). An important aspect of a stenciling program is the distribution of informational flyers that educate the neighborhood (business or residential) about stormwater pollution, the storm drain system, and the watershed, and that provides information on alternatives such as recycling, household hazardous waste disposal, and safer products.

While it is generally recognized that the potential exists for hazardous household materials to come in contact with stormwater runoff, it is unclear at present how significant this source of contamination is. As such, it is difficult to quantify the benefits to water quality from household hazardous waste collection programs. However, such programs are a preventative, rather than curative measure, and may reduce the need for more elaborate treatment controls. Programs can be a combination of permanent collection centers, mobile collection centers, curbside collection, recycling, reuse, and source reduction. Public education is extremely important in implementing this BMP.

8.4.6 Spill Prevention And Cleanup

There are two major BMPs included in this category:

1. Vehicle Spill Control
2. Aboveground Tank Spill Control

The purpose of a vehicle spill control program is to prevent or reduce the discharge of pollutants to stormwater from vehicle leaks and spills by reducing the chance for spills by preventive maintenance, stopping the source of spills, containing and cleaning up spills, properly disposing of spill materials, and training employees. It is also very important to respond to spills quickly and effectively.

Aboveground tank spill control programs prevent or reduce the discharge of pollutants to stormwater by installing safeguards against accidental releases, installing secondary containment, conducting regular inspections, and training employees in standard operating procedures and spill cleanup techniques.

Accidental releases of materials from aboveground liquid storage tanks present the potential for contaminating stormwater with many different pollutants. Materials spilled, leaked, or lost from tanks may accumulate in soils or on impervious surfaces and be carried away by stormwater runoff.

Proper handling and storage of materials is very important and should include proper labeling; development of storage and handling procedures, secondary containment procedures, spill response procedures; and adequate training and education for those involved with this BMP.

8.4.7 Dumping Controls

This BMP addresses the implementation of measures to detect, correct, and enforce against illegal dumping of pollutants on streets and into the storm drain system, streams, and creeks. Substances illegally dumped on streets and into the storm drain system and creeks include paints, used oil and other automotive fluids, construction debris, chemicals, fresh concrete, leaves, grass clippings, and pet wastes. All of these wastes can cause stormwater and receiving water quality problems as well as clog the storm sewer system itself. Increased coordination with Lancaster County Health Department efforts would be useful.

8.4.8 Connection Controls

There are three major BMPs included in this category:

1. Illicit Connection Prevention
2. Illicit Connection Detection and Removal
3. Leaking Sanitary Sewer Control

Illicit connection protection tries to prevent unwarranted physical connections to the storm drain system from sanitary sewers, floor drains, etc., through regulation, regular inspection, testing, and education. In addition, programs include implementation control procedures for detection and removal of illegal connections from the storm drain conveyance system. Procedures include field screening, follow-up testing, and complaint investigation.

Leaking sanitary sewer control includes implementing control procedures for identifying, repairing, and remediating infiltration, inflow, and wet weather overflows from sanitary sewers into the storm drain conveyance system. Procedures include field screening, testing, and complaint investigation.

Illegal connections can occur in new as well as existing developments. Improper connections in areas of new development can be prevented through inspection and other verification techniques. The first measure to prevention is to make sure that existing municipal building and plumbing codes prohibit any unwarranted, non-permitted physical connections to the storm drain system. Building and plumbing code inspectors, in addition to new land development project inspectors, must visually inspect to ensure that illegal connections are not being physically tied to the storm conveyance system. Proper documentation and record keeping is essential to the function of such inspections. Documentation helps catalog the storm drain system and is required by Federal regulations. Visual inspection, however, is not a very reliable means of verifying the status of new physical connections and their final destination. Continued monitoring throughout the entire development phase would be necessary to guarantee the new physical connections between the sanitary sewers and storm drains had been prevented through the inspection process.

Public education programs will also aid in the monitoring of illegal connections and leaking sanitary sewers by making individuals aware of evidence of unwarranted discharges to the storm drain system. A community hotline for reporting such evidence can greatly supplement the stormwater department's field screening efforts.

8.4.9 Street/Storm Drain Maintenance

There are seven major BMPs included in this category:

1. Roadway Cleaning
2. Catch Basin Cleaning
3. Vegetation Controls
4. Storm Drain Flushing
5. Roadway/Bridge Maintenance
6. Detention/Infiltration Device Maintenance
7. Drainage Channel/Creek Maintenance

Roadway cleaning may help reduce the discharge of pollutants to stormwater from street surfaces by conducting cleaning on a regular basis. However, cleaning often removes the larger sizes of pollutants but not the smaller sizes.

Most pollutants accumulate within three feet of the curb which is where the roadway cleaning should be concentrated. Catch basin cleaning on a regular basis also helps reduce pollutants in the storm drain system, reduces high pollutant concentrations during the first flush of storms, prevents clogging of the downstream conveyance system and restores the catch basins' sediment trapping capacity.

Vegetation control typically involves a combination of chemical (herbicide) application and mechanical methods. Mechanical vegetation control includes leaving existing vegetation, cutting less frequently, handcutting, planting low maintenance vegetation, mulching, collecting and properly disposing of clippings and cuttings, and educating employees.

Storm drains can be "flushed" with water to suspend and remove deposited materials. Flushing is particularly beneficial for storm drain pipes with grades too flat to be self-cleansing. Flushing helps ensure pipes convey design flow and removes pollutants from the storm drain system. However, flushing will only push the pollutants into downstream receiving waters unless the discharge from the flushing is captured and removed from the drainage system.

Proper maintenance and siltation removal is required on both a routine and corrective basis to promote effective stormwater pollutant removal efficiency for wet and dry detention ponds and infiltration devices. Also, regularly removing illegally dumped items and material from storm drainage channels and creeks will reduce pollutant levels.

8.4.10 Permanent Erosion Control

There are three major BMPs included in this category:

1. Erosion Control - Permanent Vegetation
2. Erosion Control - Flow Control
3. Erosion Control - Channel Stabilization

Vegetation is a highly effective method for providing long term, cost effective erosion protection for a wide variety of conditions. It is primarily used to protect the soil surface from the impact of rain and the energy of the wind. Vegetation is also effective in reducing the velocity and sediment load in runoff sheet flow.

Channel stabilization addresses the problem of erosion due to concentrated flows. Concentrated flows occur in channels, swales, creeks, rivers and other water courses in which a substantial drainage area drains into a central point. Overland sheet flow begins to collect and concentrate in the form of rills and gullies after overland flow length of as little as 100 feet. Erosion due to concentrated flow is typically extensive, causing large soil loss, undermining foundations and decreasing the flow capacity of watercourses.

Proper selection of ground cover is dependent on the type of soil, the time of year of planting, and the anticipated conditions that the ground cover will be subjected. In addition, mulching is a form of erosion protection which is commonly used in conjunction with establishment of vegetation. It typically improves infiltration of water, reduces, retards erosion and helps establish plants in disturbed areas.

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